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THE
OPERATING ENGINEER'S CATECHISM
OF
STEAM ENGINEERING

BY

MICHAEL H. GORNSTON
STEAM ENGINEER
IN THE DEPARTMENT OF EDUCATION, CITY OF NEW YORK,
SINCE 1902

ILLUSTRATED

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PRINTED IN THE UNITED STATES OF AMERICA

TO

MY WIFE

IN APPRECIATION OF HER LOVING SYMPATHY
AND ENCOURAGEMENT

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PREFACE

For over thirty years the author, like hundreds of other engineers and prospective engineers with whom he has come in personal contact, has searched for a book that would furnish clear and easily understood answers to questions that arise in the course of a day's work in the steam plant.

The search was in vain. All of the many books purchased proved to be incomplete. In many instances the information was incorrect, and in no case was the index so arranged as to enable the student to locate information without considerable effort and loss of time. Determined to gain theoretical as well as practical knowledge of the subject, the author enrolled with the International Correspondence Schools, attended lectures, borrowed books from public libraries, etc.

In recent years he has been frequently called upon by his fellow engineers to suggest answers to various examination questions. This led to requests, from many readers of his answers, for a book of questions and answers that would cover the subject of steam engineering as completely as possible.

The object in writing this book, therefore, was to fill a long felt need among operating engineers as well as to furnish an easily understood text for the prospective engineer and others, connected with the steam plant.

The form adopted for this book has resulted from the desire to facilitate its use by those who have not acquired studious habits. To such men, the question asked presents first a distinct image of the subject to be considered, so that the answer or explanation which follows is better understood than it would be if no question had been asked. To the progressive and advanced engineer, the man who is accustomed to books and study, this book is offered as a ready reference in which information desired can be found without difficulty or loss of time.

The answer to each question is made as short and direct as possible, giving only the information demanded by the question. When technical terms are used, they are either defined or made clear by the wording of the answer.

To aid the student in finding quickly any desired information, the book has been thoroughly indexed, each item being entered under every possible heading. The index numbers refer directly to the number of the answer and not to the chapter or page.

To illustrate the manner in which examination or other questions may be answered by the aid of this book, the author presents herewith a question asked by the Municipal Civil Service Commission at an engineer's examination.

STATIONARY ENGINEER

Que. What are the different appliances for feeding a boiler? How does each work?

See Index:

Boiler feeding apparatus 243–275, 1113, 1144–1147.
Gravity-feed apparatus 272–274.
Injectors. Action of 244.
Pumps. Boiler feed 1113, 1144–1147.

The author desires to make grateful acknowledgment to Prof. W. D. Ennis for his helpful criticism and valuable suggestions, and to the publishers, D. Van Nostrand Co., for their uniform courtesy, and wise counsel on many points of detail.

M. H. G.

January, 1922.

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HEAT AND STEAM

1. Define heat.

Heat is a form of energy.

2. What causes the sensations of warmth and cold?

All matter is composed of **molecules,** which are moving or vibrating back and forth with very high velocities. This movement of the molecules is believed to cause the sensations of warmth and cold; if the motion is slow, the body feels cold; whereas, if the motion is rapid, the body feels warm.

3. Define temperature.

Temperature is a term used to indicate how hot or how cold a body is; i.e., to indicate the velocity of vibration of the molecules of a body.

4. Describe the instrument used for measuring temperature.

The **thermometer** with which temperature is usually measured, consists of a thin glass tube, at one end of which is a bulb filled with mercury. Upon being heated, the mercury expands in proportion to the rise in temperature. Thermometers are graduated in different ways. In the **Fahrenheit** thermometer, which is the one generally used in this country, the point where the mercury stands when the instrument is placed in **melting ice** is marked 32°. The point indicated by the mercury when the thermometer is placed in **water boiling** in the open air at the level of the sea on a normal day, is marked 212°. The length of tube between these two points is divided into 180 equal parts called **degrees.**

5. What are the effects of heat when heat is applied to a substance?

The **effects of heat** most commonly observed are: (1) an increase in temperature; (2) expansion of the body, causing it to fill a greater space; (3) change of the substance of the body; for example, from a solid to a liquid or from a liquid to a gas.

6. Define (a) sensible heat, (b) latent heat.

(a) The portion of the heat applied that raises the temperature and, therefore, affects the thermometer, is called sensible heat. (b) The heat that is expended in changing a body from the solid to the liquid state or from the liquid to the gaseous state is called latent heat.

7. Define the term British thermal unit, or B.t.u.

A B.t.u. is the quantity of heat required to raise the temperature of a pound of water from 62° to 63°. It is used as a unit for the measurement of heat.

8. Is the quantity of heat, required to produce a change of 1 degree in one pound of water, equal to one B.t.u. when the temperature of the water is originally less than 62° or more than 63°?

No. It takes slightly more than one B.t.u. to raise the temperature of 1 pound of water one degree, when the original temperature is below 62°; slightly less than one B.t.u. for initial temperatures above 63° and below 140°; then slightly more again. However, the difference is so small that, for all ordinary purposes and temperatures, it may be assumed that it takes 1 B.t.u. to produce a change of 1 degree in the temperature of 1 pound of water.

9. (a) Give the mechanical equivalent of one British thermal unit (B.t.u.); (b) What is the law regarding this equivalent?

(a) 778 foot-pounds are equal to 1 B.t.u. (b) Heat may be changed to work or work to heat; 778 foot-pounds of work may produce 1 B.t.u.; and, conversely, the expenditure of 1 B.t.u. may produce 778 foot-pounds of work.

10. Define (a) specific heat; (b) latent heat of fusion; (c) latent heat of steam.

(a) The specific heat of a body is the ratio between the quantity of heat required to warm that body one degree and the quantity of heat required to warm an equal weight of water one degree. (b) This term is applied to the quantity of heat required to change a pound of a given substance from the solid to the liquid state, without change of temperature. (c) The latent heat of steam is the quantity of heat required to change one pound of water at a given temperature to steam at the same temperature.

11. Give the latent heat of fusion of water.

About 144 B.t.u. are required to change one pound of ice at 32° to water at 32°. Hence the latent heat of fusion of water is 144 B.t.u.

12. What is meant by evaporation?

The process of changing liquids into vapors by means of heat.

13. What is steam?

It is water vapor.

14. How does the change of pressure on the surface of a liquid affect its boiling point?

An increase of pressure on the surface of a liquid raises the boiling point; a decrease of pressure lowers the boiling point.

15. What is the boiling point of water under atmospheric pressure?

It is 212° Fahrenheit.

16. Define (a) saturated steam; (b) superheated steam.

(a) Steam in contact with water, such as the condition of steam in an ordinary boiler. Saturated steam has the lowest possible temperature at the given pressure. (b) Steam separated from water and heated so as to give it any temperature higher than the boiling point corresponding to its pressure.

17. Define (a) heat of the liquid; (b) latent heat of vaporization; (c) total heat of saturated steam; (d) specific volume of steam; (e) density of steam.

(a) The number of B.t.u. required to heat one pound of water from 32° F. to the boiling temperature at the existing pressure; (b) latent heat of vaporization is the quantity of heat required to change one pound of water at the boiling temperature to saturated steam at the same temperature; (c) the number of heat units required to change one pound of water at 32° to saturated steam of the required pressure; (d) the number of cubic feet of space occupied by one pound of steam of the given pressure; (e) the weight of one cubic foot of steam at the given pressure.

18. What is the difference between gauge pressure and absolute pressure?

Gauge pressure is pressure above atmospheric. Absolute pressure is gauge pressure + 14.7 pounds per sq. in. atmospheric pressure. (The steam gauges fitted on steam boilers register pressures above the atmospheric; that is, if the steam gauge is, for example, at 70 lb. the absolute pressure is $70 + 14.7 = 84.7$.)

STEAM BOILERS

19. What is a steam boiler?

It is a closed vessel in which steam is generated for power, heating, or other purposes.

20. Define (a) the water-line; (b) steam space in a boiler.

(a) The water-line is the level of the surface of the water in the boiler; (b) the steam space is the space in the boiler above the water-line.

21. Classify steam boilers according to their (a) form; (b) construction; (c) use.

(a) According to their form, boilers are **horizontal** or **vertical**; (b) according to their construction, they are **shell, flue, sectional, fire-tube,** and **water-tube** boilers; (c) according to their use, they are designated as **stationary, locomotive** and **marine.**

22. Describe the shell, or plain cylindrical boiler.

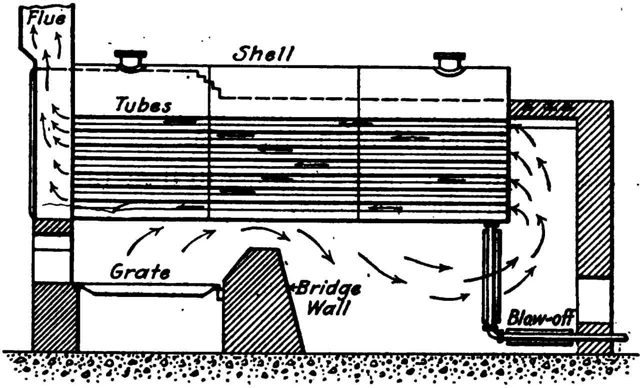
This type of boiler consists of a long cylinder, or shell, made of iron or steel plates riveted together. Boilers of this type are usually from 30 inches to 40 inches in diameter, and from 20 ft. to 40 ft. in length, although in some cases the length has been made as great as 70 ft. The heads of this boiler are either hemispherical or flat. The hemispherical heads are more generally used, as they are stronger than flat heads and require no bracing.

23. Describe the flue boiler.

A flue boiler consists of a long cylinder, made of steel or iron plates riveted together, with one or more large flues running lengthwise through the shell, below the water-line. The ends of the flues are fixed in the front and rear heads of the shell. Boilers of this type are also provided with a dome.

24. Describe the horizontal return-tubular boiler.

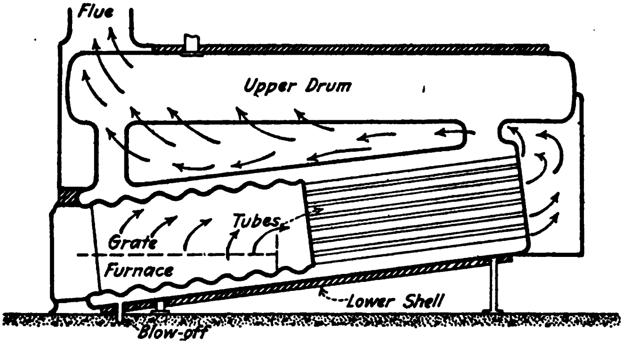
This type of boiler is a development of the principle of the flue boiler. By making the flues more numerous and smaller, the flue boiler becomes a horizontal return-tubular boiler. In this boiler, the larger proportion of the total heating surface is provided by the small flues, called **tubes.** The space occupied by this boiler is moderate in comparison with that of a flue boiler of equal steam-generating capacity. The tubes extend the whole length of the shell; their ends are expanded into the holes in the boiler heads and beaded over. A dome, which increases the steam space, is usually provided, though this is not absolutely essential. A manhole, provided either in one of the heads or on top of the shell, and one or two handholes, give access to the various parts of the boiler. Aside from its occasional liability to explosion, this boiler has proved itself best adapted to the wants of small steam users and is so largely used in the United States that it may be regarded as the standard American fire-tube stationary boiler. This type of boiler is usually supported on **brick walls** by brackets riveted to the shell. These brackets usually rest on cast-iron plates let into the brickwork, rollers being interposed between the brackets and plates to allow the boiler to expand freely. The walls are supported by vertical **buckstaves,** bolted together at top and bottom. The **furnace** is placed under the front end of the boiler shell. Behind the furnace is built the **bridgewall,** which serves to keep the hot gases in close contact with the under side of the boiler shell as they move toward the rear.



Horizontal Return-tubular Boiler.

25. Describe the Robb-Mumford boiler.

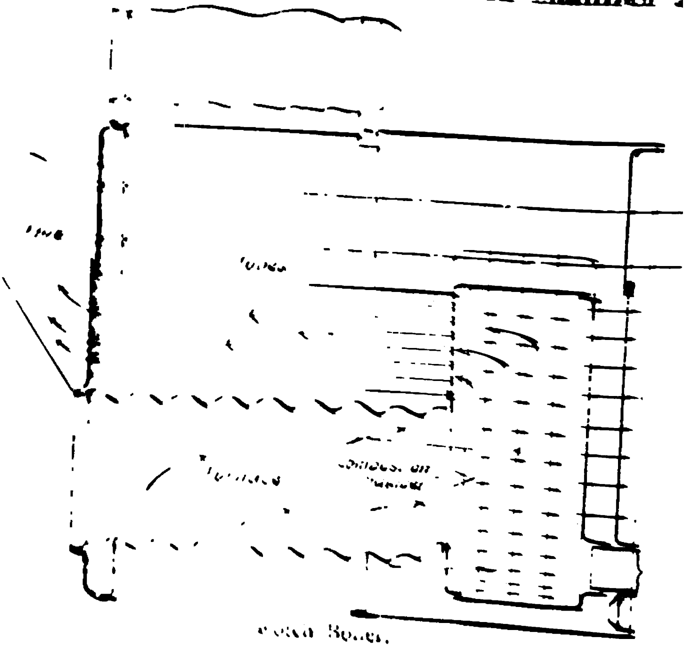
This type of boiler belongs to the class referred to as being **internally fired**, the furnace being inside the boiler. It consists of two cylindrical drums or shells which are connected by cylindrical nozzles, or necks, one at each end. The lower drum contains a cylindrical furnace fitted at one end with a **furnace front** containing a **fire-door** and an **ashpit-door**, and at the other end with a tube sheet into which are expanded the tubes. These tubes are also expanded into the rear head of the lower drum. The lower drum is inclined about one inch per foot, this inclination promoting the circulation of the water in the boiler, and also facilitating the complete emptying of the boiler, since the blow-off pipe is attached to the lowest end of the lower drum. The lower and upper drums are enclosed in a sheet-steel casing. The inside of the casing and the top of the upper steam drum are covered with non-conducting material. In operation, the water and steam bubbles circulate upward and to the rear of the lower drum, then passing up the neck into the steam drum, where the steam bubbles rise to the steam space. The water then circulates down the front neck, entering the top of the lower drum, where a **semi-circular baffle plate** causes it to flow downward.



Robb-Mumford Boiler.

26. Describe the Scotch boiler.

The Scotch boiler, while essentially a marine boiler, is also used to some extent in stationary work. It is generally fired with two, three or internal furnaces, and is made from 8 to 16 ft. in ameter, and from 7 to 12 feet long. It may be ei **single or double ended**, which means that it has naces at either one or both ends. These boilers combined in various ways with regard to the arran ment of tubes and combustion chambers to sec lightness and efficiency. They require extrem careful handling to prevent internal stresses a strains that cause leaks. The flat heads of the sh are kept from bulging by heavy stay rods and diago braces. The flat sides of the combustion chamber a



Scotch Boiler.

stayed to the shell and to the rear head by staybolts. The flat tops of the combustion chambers, called **crown sheets**, are strengthened by girder stays, or crown bars. Manholes and handholes give access to the interior of the boiler. Large **furnace flues**, extending through the boiler, open into combustion chambers. A nest of fire tubes extends from the front plates of the combustion chambers to the front head of the shell. The double-ended Scotch boilers resemble two single-ended boilers placed back to back. A double-ended boiler is lighter and cheaper and occupies less space than two single-ended boilers. In double-ended boilers, the furnace flues at each end communicate with a centrally located combustion chamber, from which the products of combustion pass through fire-tubes leading to two smoke flues, one at each end. In these types of boilers the flues, tubes and combustion chambers are surrounded by water. This gives the boiler a very large heating surface in proportion to its cubical contents.

27. Describe the Clyde boiler.

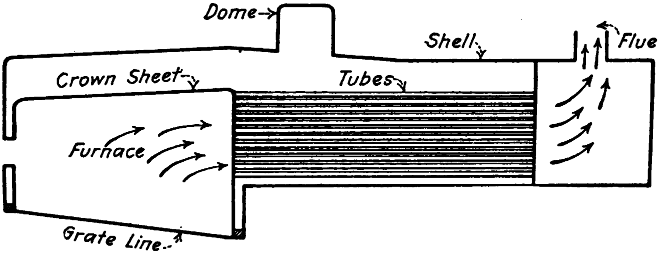
A boiler of this type consists of a large cylindrical shell, the ends of which are closed by flat heads. A large furnace flue of the type known technically as the **Morison suspension furnace flue,** extends clear through the boiler and is securely riveted to the two heads. Above and alongside of the furnace flue, parallel thereto, and below the water-line, is a nest of tubes that extend from head to head. The front ends of these tubes open into an uptake that connects with a chimney or stack. The flat heads are stayed by through stayrods, in the steam space, which prevent deflection of the heads. The remaining parts of the flat heads are supported by the tubes and the furnace flues. The furnace is placed **within the furnace flue.** The combustion chamber is formed by a thin cylindrical shell attached to the rear end of the boiler, and is lined with **firebrick or thick asbestos millboard.** The back plate is removable, giving access to the rear ends of the tubes. The feedwater passes through an internal perforated feedpipe and is discharged downward alongside the shell in small streams. The steam is collected by a dry pipe which is fairly effective in freeing the steam from water. Manholes and handholes give access to the various parts of the boiler. These boilers do not require any brickwork setting. They are bolted to the three saddles that (in marine practice) rest on and are fastened to the framing of the vessel. In outward appearance this boiler resembles the Scotch boiler. The difference between the two boilers is, that in the Scotch boiler the combustion chamber is surrounded by water; in the Clyde boiler the combustion chamber is not surrounded by water, and is simply attached to its rear head. For this reason it is often called a **dry-back** Scotch boiler.

28. Describe the Gunboat boiler.

This boiler has a cylindrical shell and flat heads. The **corrugated furnace flues** are similar to those used in the Scotch boiler and also contain the furnace. The Gunboat boiler is a modification of the Scotch boiler, made for the purpose of providing a boiler of small diameter that can be placed where headroom is very limited. The peculiarity of this boiler is that the tubes, instead of being placed above and around the furnace flues, are placed in the rear and in line with them. By this arragement of the parts, the boiler is greatly reduced in diameter, but its length is doubled. The combustion chamber is made twice the depth to compensate for its reduced height. The tubes extend from the rear end of the combustion chamber to the rear head of the boiler. The uptake or smoke box, leading to the smokestack, is attached to the rear head of the boiler. The combustion chamber is provided with **vertical tapering tubes** which connect the upper and lower parts of the water space together and add considerably to the heating surface. These tubes also assist in staying and strengthening the flat top of the combustion chamber. They are made tapering to enable the flange at the smaller end of the tube to be passed through the opening in the top sheet of the combustion chamber while the boiler is under construction. The tubes are placed with the large ends uppermost to facilitate the discharge of the steam that is generated within the tubes, which are called **Galloway** tubes. The heads are braced by the tubes, the furnace flues, longitudinal braces, and diagonal braces, or **palm stays.** The flat top of the combustion chamber is braced by sling stays. The sides and bottom of the combustion chamber are secured to the shell of the boiler by stay bolts.

29. Describe the locomotive boiler.

The locomotive boiler is used to the exclusion of all other types in railroad work; it is also largely used as a stationary boiler, and in portable combined engine and boiler outfits for agricultural purposes. The forward part of the boiler consists of a round shell; the rear part is usually of a rectangular cross-section with approximately vertical sides. The firebox is placed in the rear end of the boiler. The space left between the furnace and the outer sheets is filled with water and is called the **water space.** The tubes extend from the firebox tube-sheet to the front tube-sheet. The shell is prolonged beyond the front tube-sheet, forming the smokebox, which has a smokestack opening at the top. The boiler is usually provided with a dome. Entrance to the boiler is effected by removing the dome cap. The flat sides of the furnace shell are braced by screwed staybolts, which are riveted over on both ends. The top of the furnace, called **the crown sheet,** is strengthened by a series of crown stays. The gases of combustion pass directly from the furnace through the tubes to the smokebox and out of the stack opening. In locomotives, a **strong draft** is obtained by allowing the exhaust steam to discharge through the smokestack. The tubes of locomotive boilers are from 6 ft. to 22 ft. in length and from 1¾ to 2¼ inches in diameter. The tubes of stationary boilers of this type are usually of large diameter, as there is less demand for great quantities of steam. The various types of locomotive boilers, such as the crown-bar type, the Belpaire boiler, etc., are similar in general construction.



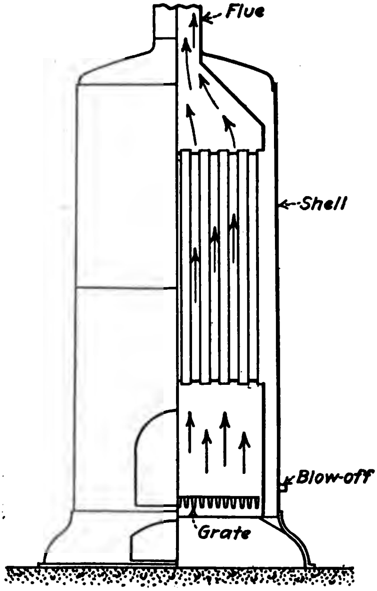
Locomotive Boiler.

30. Describe the Pennsylvania boiler.

The Pennsylvania boiler is a combination of a fi box and return-tubular boiler. The gases of combustion pass through large, short lower tubes to a combustion chamber forming an extension of the cylindrical part of the rear end of the boiler, and then return through small, long tubes to the smokebox, at the front end of the boiler, whence they discharge into the chimney. A **baffle plate** is fitted to the combustion chamber to prevent the hot gases from coming into contact with the upper part of the tube-sheet, which part is not covered by water. The firebox has a **semicircular crown sheet** which is stayed by solid crown bars. The water legs are stayed by screw stays, as in locomotive boilers.

31. Describe the vertical fire-tube boiler.

The vertical type of fire-tube boiler may be considered as a modification of a locomotive type, placed on end. The common form of vertical fire-tube boiler consists of a vertical cylindrical shell, in the **lower end** of which is the firebox. As in the locomo-



Vertical Fire-tube Boiler.

tive boiler, the shell and firebox are stayed together by staybolts, and the space between the two is filled with water, so that the firebox is surrounded by it. The boiler shell rests on a cast-iron base that forms an ash-pit. A series of vertical tubes extends from the top sheet of the firebox to the upper head of the shell. The tubes serve as stays, strengthening the flat surfaces which they connect. The upper ends of the tubes open directly into a chimney base, which is bolted to the top flue head. The gases from the furnace thus pass directly through the tubes and out of the stack. The construction of this type of boiler does not generally permit the use of manholes, but handholes are placed in convenient positions for cleaning out mud and sediment. Since the tubes extend to the upper end of the boiler, their upper ends pass through the steam space above the water-line. This type of boiler is said to be **flush-tubed.** In such case the tubes are liable to become overheated and to collapse when the boiler is forced. In some forms of vertical boilers a chamber, or smokebox, extends down from the upper end of the cylindrical shell, so that its bottom plate is always below the water line. The upper ends of the tubes are expanded into the lower plate of this chamber, and therefore the tubes are always surrounded by water. This form of boiler is called the **submerged-tube boiler.**

32. Describe the portable and semiportable boilers.

Portable and **semiportable** boilers are used wherever conditions require the installation of a temporary power plant capable of being moved from place to place. In some forms of semiportable boilers, the bottom of the **firebox,** instead of opening into an ash-pit, **is closed by a continuation of the water legs,** and the furnace is, therefore, entirely surrounded by water. A boiler thus constructed is said to be **wet-bottomed.** Some wet-bottomed boilers have an **ash-pit door in the center of the bottom** instead of in the front or head. The cylindrical part of the boiler is supported by a cast-iron cradle. The firebox end of a semiportable boiler of the locomotive type rests on a brick or concrete foundation. The portable steam power outfit consists of a wet-bottomed firebox boiler mounted on wheels and carrying a steam engine bolted to its top.

33. What is the difference between the fire-tube and the water-tube type of boiler?

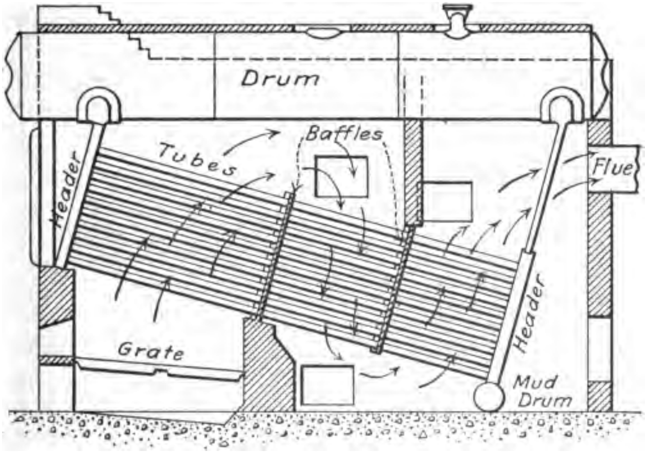
In the fire-tube boiler, the water surrounds the tubes, the flame and hot gases being inside the tube. In the water-tube boiler, the water is inside the tubes, which are surrounded by the fire and hot gases.

34. State some of the advantages of a water-tube boiler.

An accident to any one tube or fitting, in a water-tube boiler, does not necessarily involve the destruction of the whole boiler. For that reason they are commonly known as **safety-boilers.** The heating surface, in this type of boilers, is much more effective than an equivalent area of surface in the ordinary tubular boilers. The circulation is rapid, and involves the entire boiler, keeping it at nearly constant temperature and tending to cause the deposit of all the sediment at the lowest point. The water is divided into small bodies, the boilers steam quickly, and are sensitive to slight changes of pressure or to conditions of the fire. The arrangement of a water-tube boiler is such as to form a flexible construction, any member being free to expand without unduly stressing any other member, which tends to prolong the life of the boiler. Soot accumulates within a fire-tube, and it may become filled, while the water-tube holds the soot only on the top surface. Many water-tube boilers are of sectional construction, and hence may be transported and erected more readily than other types.

35. Describe the Babcock & Wilcox water-tube boiler.

This boiler has large, straight tubes, and is classified as an **inclined** water-tube boiler. It consists essentially of a main horizontal drum, or drums, and of a series of inclined tubes. The tubes, at their upper and lower ends, are expanded into hollow cast-iron or wrought-steel **manifolds,** known as **headers.** The headers are connected at their upper ends, by short tubes, to wrought-steel **cross-boxes,** which are riveted to the lower side of the drum. Handholes are placed in the headers for the purpose of inspection, cleaning and repairs. All of the rear headers are connected at their lower ends to a **mud-drum.** A pipe connects the lower side of this drum to the blow-off valve. Several handholes serve for cleaning. Manholes are provided in each of the heads of the drum. The parts of the boiler so far mentioned are known as the pressure parts, and are suspended from structural steel supports by U-shaped hangers. The **brick setting** does not support the pressure part of the boiler, serving only to enclose the furnace and to form the gas passages about the boiler. The **furnace** is usually placed **under the high end of the tubes.** The **bridge wall,** the so-called **hanging wall,** and the **flame bridges,** are so arranged as to form a gas passage, from the furnace to the damper in the outlet, by means of which

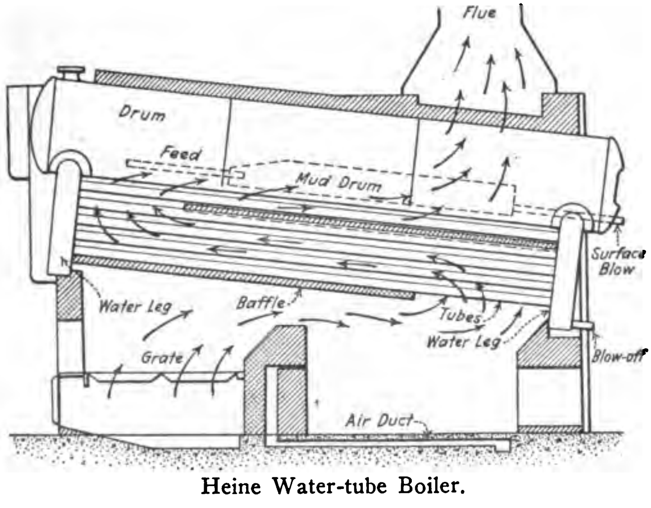


Babcock & Wilcox Boiler.

the gases are usually passed across the tubes three times. In order to bring the gases into the most intimate contact with the tubes, the headers are **staggered.** The feed water is introduced into the drum through a feed pipe and is discharged under a **baffle plate.** The steam is collected in a **dry pipe** at a considerable distance from the front end of the drum and is discharged through nozzles, one being the safety-valve connection and the other the connection to the steam main. A water column, with gauge-cocks and water gauge-glass, is connected to the steam and water spaces of the drum. The small dimensions, together with the considerable thickness, of the headers and mud-drum, are such that these parts require no bracing. All other pressure parts of the boiler are either cylindrical or spherical in form and require no bracing of any kind. A considerable portion of the solids contained in the boiler water is deposited in the mud-drum, and blown out at intervals through the blow-off valve. Small door openings in the brick setting permit the insertion of a steam hose nozzle for blowing dust from the external surface of the tubes. Doors also give access to the interior of the brick setting.

36. Describe the Heine water-tube boiler.

The Heine boiler consists of a large main drum, which is above and parallel with a nest of tubes. Both drum and the tubes are **inclined** at an angle that brings the water to about one-third the height of the

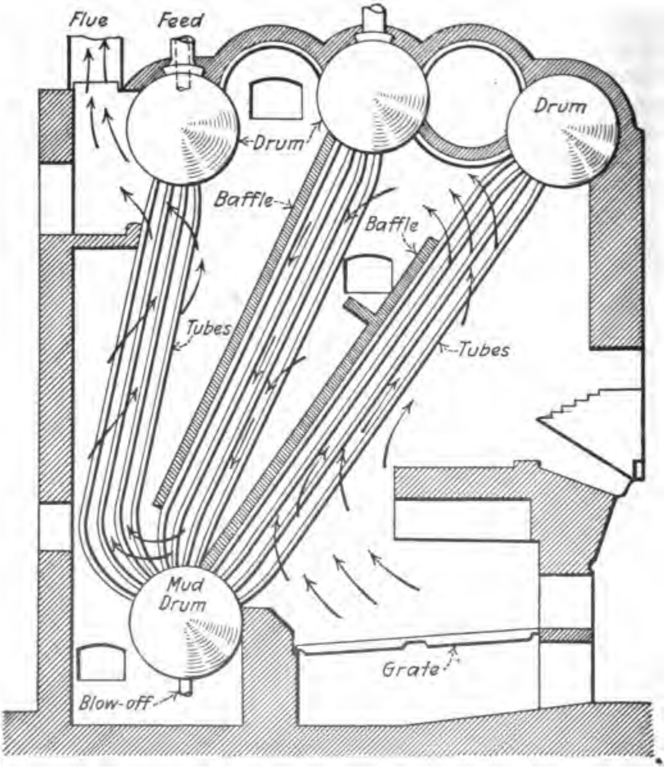


Heine Water-tube Boiler.

drum in front and to about two-thirds the height in the rear. The ends of the tubes are expanded into large flange-steel water legs. These legs are flanged and riveted to the shell, which is cut out from about one-fourth of its circumference to receive them. The drum heads form segments of a sphere, and therefore do not need bracing. The water legs form the natural support of the boiler, the front water leg being placed on cast-iron columns that form part of the boiler front, while the rear water leg rests on rollers, which can move on a cast-iron plate bedded in the rear wall. These rollers allow the boiler to expand freely when heated. The boiler is enclosed by a brickwork setting in the usual manner. The **bridge wall is made hollow,** and has openings in the rear to allow air to pass into the chamber and mix with the furnace gases. In the rear wall is an arched opening, which is closed by a door and further protected by a thin wall of firebrick. When it is necessary to enter the chamber the wall may be removed and afterward replaced. The feed water is brought in through a feed pipe, which passes through the front head. The water flows into a **mud-drum,** which is suspended in the main drum below the water-line and is thus completely submerged in the hottest water in the boiler. This high temperature is useful in precipitating the impurities contained in the feed water, which settle in the mud-drum and may be blown out through the blow-off pipe. Layers of firebrick are laid at intervals along the rows of tubes, and act as **baffle plates,** forcing the furnace gases to pass back and forth lengthwise over the tubes. The gases finally escape through the chimney placed above the rear end of the boiler. The steam is collected and freed from water by a perforated dry pipe. A manhole is placed in the rear head of the drum. The flat surfaces of the water legs are stayed together by staybolts, which are made hollow to give access to the outside of the tubes. A steam hose nozzle can be passed in turn through each of these hollow staybolts for fully three-quarters of the length, thus blowing the soot and ashes from the tubes. In front of each tube a handhole is placed to give access to the interior of the tube.

37. Describe the Stirling water-tube boiler.

This type is known as the **bent-tube** stationary water-tube boiler. It consists of a **mud-drum** connected with three upper drums by three banks of tubes, the rear bank being almost vertical and the front bank having a considerable forward inclination at the top. The curved tubes allow the different parts of the boiler to expand and contract freely without excessive strains. The boiler is enclosed in a **brickwork setting** which is provided with various openings, so that the interior may be cleaned or repaired. The. boiler is supported by structural steel supports underneath the ends of the **steam drums,** the mud-drum hanging from the tubes so as to allow the boiler to expand freely. The **bridge wall** is built free from the mud-drum and with its top 1½ inches from the tubes so as to permit the mud-drum to move freely



Stirling Water-tube Boiler.

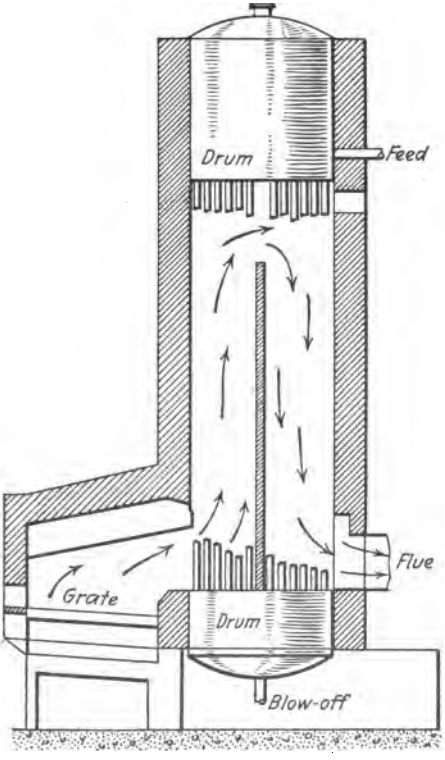
as the boiler pressure is raised. An arch and **baffles**, above the grates, direct the/course of the heated gases, causing them to pass up and down between the sets of tubes. The arch becomes heated to a white heat and thereby promotes thorough combustion, and also serves to heat the incoming air when the furnace doors are opened, thus protecting the tubes from being chilled at such times. The feedwater enters the rear upper drum and is distributed by a **feed-pan** in the drum. It then descends through the rear bank of tubes to the mud-drum, which is provided with a blow-off pipe to remove the sediment. From the mud-drum, the water passes upward through the front bank of tubes and is partly vaporized as it rises; the steam separates from the water in the upper front drum and passes thence through the upper tubes to the middle drum, where it reaches the steam outlet. The water passes through a lower set of tubes to the middle drum and thence downward through the middle bank of tubes to the mud-drum, where it is again carried by circulation into the front bank. A third set of tubes is provided to connect the middle and rear drums to equalize pressures and to conduct to the middle drum the steam that is generated in the rear drum. The steam pipe and safety valves are attached to the middle drum. The chimney base is usually located behind the rear upper drum, although the connection may be made on the upper part of the rear wall. The water column with its fittings is connected to the upper or middle drum. The drums are provided with large manholes.

38. Describe the Morrin climax boiler.

It is a water-tube boiler that has a central or main vertical shell fitted with a large number of **loop-like** tubes. The ends of the tubes are expanded into the shell. The furnace is **circular** and is provided with **four furnace doors** in order to give free access to the fire. A **deflector plate** is fitted to the shell a little above the water level, which tends to throw back any water carried up by the steam. The upper part of the central shell is divided by a series of diaphragms into a series of superheating chambers, through which the steam is compelled to circulate successively by the connecting loop-like tubes. The steam thus becomes thoroughly dried and somewhat superheated before it enters the main steam pipe. The feedwater passes through a flat spiral **feed-coil** resting on top of the tubes, where it is heated to a high temperature. From the feed-coil it passes downward through a pipe, and enters the bottom of the shell through an internal feedpipe. The water column is connected to the top and bottom of the central shell. The safety valve is attached to a T placed in the main steam pipe close to the boiler.

39. Describe the Wickes boiler.

The Wickes boiler is distinctly a **vertical water-tube** boiler. It consists of two drums united by a



Wickes Boiler.

number of long straight tubes and encased in **brickwork.** The tubes are arranged in two banks separated by a vertical tile **deflector.** The **furnace** is located at one side of the boiler and the products of combustion pass upward along the first section of tubes, over the top of the deflector, down along the second section of tubes, and out through the opening near the base of the setting, to the chimney. The top drum is called the **steam drum** and the lower one the **mud-drum.** Each drum has a dished head provided with a manhole. The feedwater enters the steam drum near the bottom, through a pipe at the side farthest from the furnace. The water-line in the steam drum is at a sufficient height to completely submerge the water tubes. The water passes down the rear bank of tubes, called **down-comers,** into the lower drum, and then up through the front bank of tubes, called **risers,** in front of the deflector. A **baffle plate** is placed above the risers in the steam drum to deflect the water to the rear and prevent particles of water from being carried through the steam outlet in the center of the top of the drum. The boiler is supported by brackets fastened to the mud-drum and resting on the brickwork. The boiler and the setting are free to expand independently of each other. Several doors are placed in the setting so that the exterior of the boiler may be inspected or cleaned.

40. Describe the Hazelton boiler.

This boiler is sometimes called a **porcupine boiler,** because of the peculiar arrangement of the tubes. It consists of a central vertical cylinder, or shell, with a large number of radial tubes having their inner ends expanded into holes in the shell and their outer ends closed. The grate surrounds the cylinder near the bottom. The inner ends of the grate bars rest on a ring supported by brackets riveted to the shell; the outer ends rest on a plate on the brickwork enclosing the ash-pit. The boiler rests on a circular cast-iron base placed on a **masonry foundation.** The boiler and furnace are enclosed in the **brickwork** that supports the chimney. The brickwork is built up square to the height of the lower tubes, and circular above that point. The furnace brickwork is encased in sheets of steel riveted to angle irons at the corners and reinforced by angle and T bars riveted to them. An air space is usually provided between the brick lining and the casing to decrease the radiation. The top of the furnace casing supports a circular plate on which is built the brick casing above the furnace. The circular casing is enclosed in sections of sheet steel bolted together. The **firebrick lining** of the furnace is built so as to slope inward at the top and deflect the flame against the cylindrical **standpipe** of the boiler. The lower end of the standpipe below the grates forms a settling chamber and **mud-drum.** It is fitted with a blow-off pipe and a manhole opposite one of the ash-pit doors. The blow-off pipe enters the mud-drum below the grate and terminates in a cone-shaped nozzle, over the center of, and close to, the lower head. The feed-pipe enters the shell below the grate and extends vertically nearly to the water-line in the boiler. It then passes downward through the axis of the boiler and delivers the water through a spraying nozzle at the level of the grate. The steam outlet is through a heavy nipple screwed through the center of the top head of the steam drum. A T on the outer end of the nipple provides openings for the steam pipe and the safety valve. A handhole is located on the end of the pipe below the safety valve, which is uncovered to afford ventilation to the interior of the boiler when it is necessary for a man to enter it. The nipple terminates at its lower end in a flange to which is bolted a blank flange. This blank flange closes the top of a short length of large pipe suspended from it. A diaphragm is attached to the lower end of the pipe and the shell of the boiler and closes the annular space between them. From the central pipe a large number of small pipes radiate horizontally and extend into the boiler tubes nearly to their outer ends. The steam flows from the central pipe through the small pipes into the boiler tubes, and thence backward into the top of the steam drum, whence it passes out between the two flanges. A drip pipe is suspended from the diaphragm and extends a short distance below the water level in the boiler. Two firing doors are located at one side of the furnace, and several doors are conveniently located in the brick setting, so that an examination can be made of the exterior of the boiler shell and tubes.

41. Describe the See water-tube boiler.

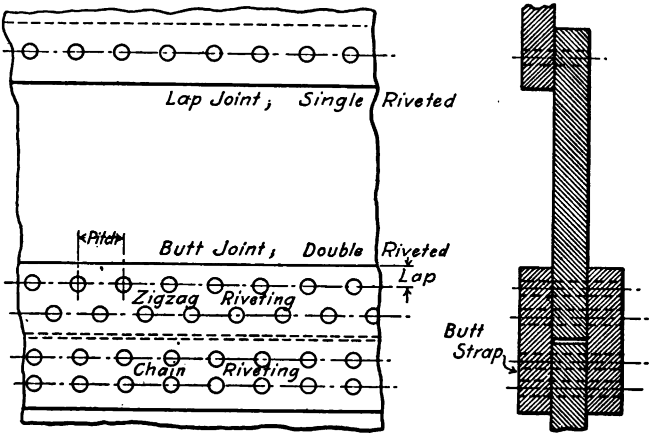
The See boiler is of the straight **inclined-tube** type, and is self-contained. The boiler consists of a **steam drum,** two **water** or **mud-drums** and two nests of tubes. Like all boilers of this class, it has a large heating surface and makes steam rapidly. The tubes being straight and accessible, can be cleaned of scale—a most important feature in any boiler. The weight of the steam-generating part, consisting of drums and tubes, is supported from the steam drum and not on the mud-drums, as is the usual custom with boilers of this type. This permits the tubes to expand freely without bringing undue strain on them. The safety valve, gauge glass and steam gauge are attached to the front end of the steam drum. The inside tubes of each nest are the ones most exposed to the intense heat of the fire. The water in them consequently expands and rises to the steam drum. The outside tubes are located in a relatively cool place. Water therefore flows **down** them to the mud-drums to take the place of that flowing up the inside tubes. A steady and rapid circulation of the water is thus established.

42. For boiler work in general, what advantages has machine riveting over hand riveting?

The advantages are as follows: (1) The plates that are being riveted can be held together with greater force; therefore, a tighter joint can be made. (2) The holes in the plates can be filled better, because the rivet shank is caused to spread out by the heavy pressure applied to upset the rivet and to form the head. (3) It is faster and cheaper, if many rivets are to be driven.

43. Define (a) lap joint; (b) butt joint; (c) longitudinal joints; (d) girth joints; (e) pitch of the rivets in joints.

(a) A joint or seam formed by having two overlapping plates joined together by one or more rows of rivets, is called a **lap joint**; (b) if the plates are placed edge to edge and the seam is covered with a narrow plate or strap, on one or both sides of the plates, the joint so formed is called a **butt joint**; there are one or more rows of rivets on each side of the edges in contact; (c) joints running lengthwise of the boiler are called **longitudinal joints**; (d) joints running around the circumference of the boiler are called **girth seams or joints.** These seams are also called **transverse**, or **circumferential joints** or **seams**; (e) the **pitch** of the rivets is the distance from center to center of the rivet holes in the same row.



Riveted Joints or Seams.

44. (a) Define lap in boiler plate joints; (b) what is it equal to?

(a) The distance from the center of the rivet hole to the edge of the plate is called lap; (b) it is usually equal to 1½ times the diameter of the rivet hole.

45. Define (a) chain riveted; (b) zigzag-riveted joints.

(a) **Chain riveted** means that the rivets in the two or more rows are placed in line. (b) **Zigzag-riveted** means that the rivets are staggered.

46. Define butt strap or welt strap, or simply welt.

The narrow strap or plate used to cover the seam on one or both sides of a butt joint, is called a **butt**, or **welt strap.**

47. What is meant by calking?

By **calking** is meant the forcing of the edge of a rivet head, or sheet or strap, into close contact with a plate, by means of a special tool made for that purpose.

48. What is a steam dome on a boiler?

It is a cylindrical vessel, usually vertical, riveted to the top of the boiler.

49. What is the purpose of a steam dome?

The purpose of a **steam dome** is to have an auxiliary steam space for dry steam.

50. What is a steam drum?

It is an auxiliary cylindrical receptacle for steam with flat or dished ends, and is connected directly to the boiler shell by one or more nozzles.

51. What is known as a mud-drum?

A drum, usually cylindrical in form, sometimes attached below the bottom of the boiler to provide a quiet place for the collection of mud and sediment held in suspension in feedwater. In many water-tube boilers, one or more mud-drums form part of the structure, serving primarily to distribute the feedwater to the tubes and incidentally to collect mud and sediment.

52. What holes, or openings, are provided in steam boilers and for what purposes?

In all types of boilers a number of holes, or openings, must be provided in the shell, heads, domes, or drums, for the outlet of steam, for the inlet and outlet of water, and for the purpose of cleaning, inspection and repairing. Each opening is designated in accordance with the purpose it serves: feedwater hole; steam and water gauge holes; washout hole, or handhole; manholes.

53. Describe the method used for closing washout or handholes and manholes.

A cover, made of either cast-iron or steel, is closely fitted to the plate around the opening. The cover and opening are made elliptical to permit the passing of the cover through the hole, the cover being on the inside of the boiler. A **bridge,** or **crab,** is made of cast-iron, steel, or malleable iron, and has a central hole to allow it to slip over a bolt which has its head countersunk into the cover. To make a tight joint, a ring or **gasket** made of sheet rubber or other pliable, waterproof material, is placed between the cover and the inside of the boiler plate. A washer is placed between the nut and the crab to enable the nut to be readily tightened without disturbing the position of the crab. Round washout holes are closed with brass plugs called **washout plugs.** In general construction, a manhole and its cover do not differ materially from a handhole and its cover, except that they are larger, and are often supplied with two bridges or crabs instead of one.

54. **Why is the long axis of a manhole always cut parallel to the girth seams?**

Because the boiler is twice as strong through a transverse plane as through a longitudinal plane.

55. **Name the various forms of boiler heads.**

There are: **flat** boiler heads; **dished** heads, which are either **convexed** or **concaved**; and combination convexed and concaved heads.

56. **Why must flat boiler heads always be well supported by stays and braces?**

Because flat heads are not self-supporting and tend to bulge when the boiler is under pressure.

57. **Give instances where (a) the flat head, (b) the dished head, is used.**

(a) The flat head is used for horizontal return-tubular boilers, flue, locomotive-type, and vertical boilers. (b) The dished head is used in plain cylindrical boilers of small diameter, and for steam drums, mud-drums, oil tanks, air-storage reservoirs, etc.

58. **In boilers having a steam dome, how is communication between the steam dome and the steam space of the boiler established?**

Communication is established either by a single large hole or a series of small holes cut through the shell plate below the dome. To compensate for the loss of strength occasioned by the cutting of a large hole through the sheet, **reinforcing** or **compensating rings** are applied around the edge of the hole.

59. How are steam dome tops usually closed?

In most boilers having a steam dome, the top is closed by a **dished** or **flat** steel head. The dished head, being the strongest, is generally used. In boilers for locomotives it is necessary to have a large opening in the dome head to permit the erection of the throttle valve, which is nearly always placed inside the dome. In this type of dome head a **dome ring,** flanged from heavy steel plate, and a **dome cap** pressed from steel plate, are used. The upper surface of the dome ring and the lower surface of the dome cap are machined, a copper gasket being placed between the surfaces to make a steam-tight joint. The dome cap is bolted to the dome ring by means of studs and nuts

60. How are steam and water pipes attached to boilers?

If the pipes are rather small and the plate is relatively thick, they may be screwed directly into the plate; but if the pipes are comparatively large, the plate must be reinforced where the pipes enter. The manner in which plates are reinforced **at pipe openings** depends somewhat on the size of the pipe and the thickness of the plate, and (in case a boiler fitting is attached) on the character of the fitting. Small openings for pipes not exceeding 1½ inches in diameter usually have the hole reinforced with a **liner,** which is riveted to the inside of the shell plate. Openings for **blow-off,** attached to the bottom of the rear course, have the hole reinforced by an **outside circular liner.** For large pipes, threaded steel flanges are used.

61. In the case of a blow-off opening, why is the reinforcing liner riveted to the outside and not to the inside of the shell plate?

Were the liner to be placed on the inside of the boiler, more or less sediment would be retained in the boiler on account of its presence there.

62. Define the term stay or brace.

The term stay or brace is applied to a part designed to strengthen and to prevent deformation of plates not strong enough in themselves to resist safely the steam pressure that the boiler is intended to carry.

63. Classify the stays used in bracing boilers.

There are three general classes, **direct stays, diagonal stays,** and **girder stays.**

64. Describe the various direct stays.

Direct stays are given various names in accordance with their shape, construction, and application. The **screw staybolt** is used for bracing in the small water spaces of the locomotive type and vertical boilers; there is also the **hollow staybolt,** with a 3/16 or 1/4 inch hole drilled into one or both ends to a depth of from 1 inch to 1 1/4 inches. The hole, which is called a **telltale hole,** is sometimes extended through the staybolt; the **stayrod,** or the **end-to-end stay,** is a long stay passing through the boiler from head to head. The **flexible staybolt** has its inner end threaded and screwed into the firebox sheet; the outer end is given a spherical shape and is seated on a spherical seat formed in a bushing which is screwed into the outside sheet. The staybolt thus rocks freely in the seat. A cap nut is screwed over the bushing to make a steam-tight joint. The threaded end of the staybolt is riveted over after having been screwed home.

65. Classify the various diagonal stays.

The **radial** stays, the **palm** stay, the **gusset** stay, and the **crowfoot** braces, are extensively used in bracing boilers.

66. How are girder stays usually constructed?

The girder stay, or **crown bar** as it is usually called in locomotive work, consists of two flat wrought-iron or steel bars which are riveted or welded to blocks placed between them at each end. To prevent the bars from spreading, a number of **spools** or **distance pieces** are placed equidistant between the bars, and a rivet is put through the bars and each spool. The crown-bar ends are formed so that they rest partly on the crown sheet and partly on the side furnace sheet. The crown sheet is connected at intervals to the crown bars by means of special rivets called **crown-bar rivets.**

67. What is meant by a furnace flue?

In internally fired boilers, the furnace is often cylindrical in form; such furnace is usually spoken of as a **furnace flue.**

68. Classify the various furnace flues.

The **plain cylinder,** the **built up** or **sectional,** the **corrugated,** the **ribbed,** and the **suspension** furnace flues.

69. Describe the plain cylinder furnace flue.

This form consists of a plain cylinder of wrought-iron or steel plate, which may have a riveted longitudinal seam or may be welded. If the furnace flue is comparatively large and conditions are such as to call for a high steam pressure, the flue is stiffened by means of strengthening rings, which are attached to the outside, where they are in contact with the water in the boiler. The strengthening rings are made of angle iron and encircle the flue, from which they are separated by a spool placed around each rivet. The spools hold the ring away from the flue and thus provide for a free circulation of water between them. The circulation of water next to the flue protects it from injury by the fire.

70. Describe the built-up or sectional flue.

This form of furnace flue is made in sections united in such a manner as to secure great strength with comparatively thin material. The method of construction varies. An excellent method of joining plain flue sections is by means of a U-shaped ring called a **Bowling ring.** This ring not only stiffens the furnace flue but also permits considerable expansion and contraction.

71. What good feature is embodied in corrugated furnace flues?

The good feature in corrugated furnace flues is that the corrugations serve to strengthen the flue considerably, and permit the flue to expand and contract freely in the direction of its length without subjecting the combustion chamber and the front head of the boiler to undue strain.

72. Describe the ribbed furnace flue.

It is a cylindrical flue with ribs 1⅜ inches in height and 9 inches from center to center of ribs. The thickness of the flue must be not less than 7/16 inches and the length of the plain part at the ends must not exceed 9 inches.

73. Explain the purpose of boiler tubes.

The purpose of boiler tubes is to increase the heating surface of the boiler and thereby increase its steaming capacity. The tubes also divide the water and heated gases into small bodies, thereby greatly facilitating the transmission of the heat from the gases to the water.

74. How are the sizes of boiler tubes designated?

The sizes of boiler tubes are designated by their **outside** diameters to distinguish them from pipes, which are designated by their inside diameters. Tubes more than six inches in diameter are usually called flues.

75. Explain the purpose of the combustion chamber.

The purpose of the combustion chamber is to provide a place for the unconsumed gases to be thoroughly mixed with air, which promotes their complete combustion.

76. Why must provision be made to regulate the quantity of air admitted to the combustion chamber?

Because more air is required under some conditions than under others. Large quantities of air are required if bituminous coals are used; while with hard, or anthracite, coal much less air will be needed; also because if the gases are cooled below the temperature of ignition by too much air they will be carried to the smokestack unconsumed.

77. Describe the construction of a combustion chamber in an internally fired boiler.

In internally fired boilers, the chamber is constructed of material similar to that used for the shells and heads of boilers of that class, and the plates are joined together in a manner similar to that employed in the construction of the boiler. Combustion chambers are built into the boilers and are designed to sustain safely the steam pressures that are carried in the boilers to which they belong. The shape of a combustion chamber depends on the form of the boiler of which it is a part.

BOILER FITTINGS

78. What is the object of a safety valve?

The object of a safety valve is to prevent the steam pressure from rising above a fixed limit.

79. What is meant by a lever safety valve?

A safety valve in which the valve is held down to its seat by the pressure of a weighted lever on the valve stem.

80. What is meant by a spring-loaded, or pop, safety valve?

A safety valve in which the valve is held down by a helical spring, the tension of which can be altered by a screw cap.

81. Why should the spring, or pop, safety valve be preferred?

Because pop safety valves open and close very promptly, while the lever safety valve does not open fully until the pressure in the boiler exceeds, by several pounds, the pressure the valve is set for.

82. Why should safety valves be connected directly to the boiler?

So that there is no possible chance of cutting off communication between the boiler and the safety valve.

83. What should be done to prevent the safety valve from corroding and thereby sticking fast to its seat?

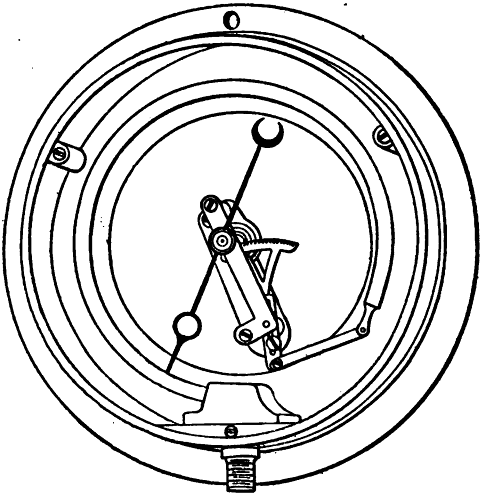
The valve should be examined occasionally and raised frequently, so as to keep it in good working order.

84. What is the object of a steam gauge?

To indicate the pressure contained in the boiler.

85. How are steam pressure gauges usually graduated?

Steam pressure gauges are usually graduated to indicate the pressure above that of the atmosphere, in pounds per square inch.



Typical Pressure Gauge.

86. What is known as a vacuum gauge?

Gauges indicating a pressure below that of the atmosphere are known as vacuum gauges.

87. How are vacuum gauges graduated?

Vacuum .gauges are usually graduated to show in inches of mercury how much the pressure has been decreased below that of the atmosphere.

88. What are known as compound steam gauges?

Gauges in which the left hand part of the dial indicates vacuum in inches of mercury, and the right hand part indicates pressure in pounds per square inch above the atmospheric pressure.

89. How does a siphon, usually placed between the steam gauge and the boiler, protect the gauge from injury from heat?

The siphon in a short time becomes filled with water of condensation, which protects the spring of the gauge from the injury the hot steam would cause.

90. What is a gauge-cock and what is its object?

A gauge-cock is a simple cock or valve attached either directly to the boiler, or to the water column, for the purpose of ascertaining the level of the water in the boiler.

91. How many gauge-cocks are employed and where are they placed?

Three gauge-cocks are generally employed. The lowest is placed at the lowest level that the water may safely attain, and the uppermost at the highest desirable level. The third cock is placed midway between the other two.

92. What is the object of a water gauge and where is it placed?

The object is to show the water level in the boiler. It is placed so that its lower end communicates with the water space of the boiler and its upper end communicates with the steam space. The gauge should be so located that the water will show in the middle of the gauge glass when at its proper level in the boiler.

93. What is the objection to having glass water gauges and gauge cocks connected directly to the boiler?

The violent ebullition at the surface of the water will cause them to indicate an uncertain or possibly a wrong water level. The **water column** is used to overcome this objection.

94. What are the purposes of the high-and-low water alarm and fusible plug?

The purpose of the high-and-low water alarm and fusible plug is to give an audible warning of a shortage or a surplus of water.

95. Describe a fusible plug and its action.

A fusible plug consists of a threaded brass plug filled with some alloy which has a low melting point. The fusible plug when covered with water is kept from melting by the comparative coolness of the water; but should the water sink low enough to leave the top of the plug uncovered, the filling melts and allows the steam to escape, thus giving warning of the shortness of water.

96. Where should a fusible plug be located?

The location of a fusible plug depends on the type of boiler used, but in general, it should be so located that it will prevent the overheating of the parts exposed to the fire.

97. **What care should be given a fusible plug?**

It should be removed regularly and examined to see that the filling is not covered by hard scale. The filling should be removed and replaced at least every six months, or a new plug installed.

98. **What is the purpose of a dry-pipe in a boiler?**

It is used in order that the steam drawn from the boiler may be as free as possible from particles of water suspended therein.

99. **Describe the construction and principle of action of the steam whistle.**

It consists of a bell, which is a hollow cylinder closed at the top and open at the bottom, and is held in position by a stud that passes through the center and is secured at the upper end by means of a screw and a jam nut. The hollow base has a narrow circular orifice that communicates with a steam pipe and valve. As the steam rushes out of the orifice in an upward direction, toward the mouth of the bell, it slightly compresses the air contained in the bell. The air, being elastic, will not remain compressed, but will spring back slightly toward the inrushing steam, to be again forced back as before, thus causing vibrations. These vibrations continue as long as steam is permitted to flow, and are communicated to the surrounding atmosphere, thus producing sound. The tone may be changed to a higher pitch by lowering, or a lower pitch by raising, the bell.

100. **What forms of valves are generally used for the purpose of controlling the flow of steam and water?**

The **globe** valve and the **gate** valve.

101. **Where is a gate valve preferable to a globe valve?**

The gate valve is preferable where it is desired that there should be the least possible resistance to the flow of the fluid.

102. **Why are by-passes desirable on or around live-steam valves of 6 inches and upward?**

Because by first opening the small valve, the pressures on the two sides of the valve are equalized, thus making the valve easy to open.

103. What is the purpose of a pressure-reducing valve?

To give a uniform low pressure from a varying high pressure.

104. What is the purpose of a check valve?

To permit a fluid to pass through it in one direction only, and to close automatically whenever the flow of the fluid is reversed. They are designated as swing check-valves and globe check-valves. They are made in different forms, as vertical, horizontal and angle check-valves.

105. What is the purpose of a steam separator?

To remove the entrained water, or oil, dirt, and other impurities, from a current of steam flowing through a pipe.

106. What is an exhaust head?

A special form of **separator** that is placed on the end of the exhaust pipe of a non-condensing engine or pump, in order to catch the water of condensation and prevent it from being scattered over roofs, etc., in the vicinity of the exhaust outlet.

107. What is the purpose of a superheater?

To superheat the steam so that it will contain more heat than would the same weight of saturated steam, and thus insure increased engine economy.

108. What is the purpose of a draft damper?

The purpose of a draft damper is to regulate the draft, so that the steam pressure can be kept as nearly uniform as possible, and to make the fire burn evenly over the entire grate surface.

109. Explain briefly the construction and operation of a draft damper or regulator?

A draft damper generally consists of a thin plate which may be placed in either the uptakes or in the stack. The plate is fastened to a damper rod, and is opened or closed by a handle, operated by hand or automatically. Closing the damper reduces the draft area and in consequence the volume of gases passing into the chimney. This reduces the air supply which in turn regulates the intensity of the fire and the generation of steam.

110. State briefly the operation of an automatic damper regulator.

Automatic damper regulators are either steam-actuated, or hydraulically operated. In the steam actuated regulator the steam by acting on a diaphragm causes the displacement of a valve, which admits steam into a cylinder, the piston of which is connected to the damper. In hydraulically operated regulators the movement of a diaphragm under variation of the steam pressure operates an admission valve, admitting water under pressure to a cylinder, the piston of which is connected to the damper.

111. Explain the purpose of a steam trap.

The purpose of a steam trap is to remove periodically all water of condensation from steam pipes, steam heating systems, separators, and similar apparatus, without the waste of steam.

112. How are steam traps generally classsified?

They are generally classified as **open traps**, and **closed traps.**

113. Define (a) an open trap; (b) a closed trap.

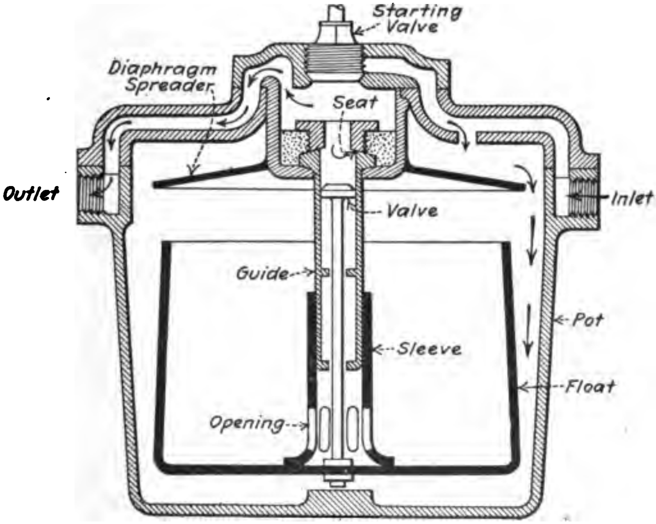
(a) An open trap is a trap constructed in such a manner that it can only discharge into a vessel in which there is a lower pressure than in the trap. (b) A closed trap is a trap constructed in such a manner that it can discharge water of condensation from a system in which there is a low pressure into a vessel in which there is a high pressure.

114. Describe briefly the construction and operation of a float trap.

A float trap consists of a chamber containing a hollow copper float having a valve at its lower end and a guide at its upper end. The water of condensation enters the trap at the top through a pipe and leaves the trap at the bottom through a pipe attached to a nipple containing the valve seat for the valve. The operation is as follows: When the trap is empty, the weight of the float holds the valve to its seat. When enough water has run in the trap, the float rises, thus opening the outlet and allowing some water to escape. As soon as sufficient water has run out of the trap, the float drops and the outlet is closed again by the valve and the operation may be repeated.

115. Describe the construction and operation of a bucket trap.

A bucket trap consists of a body containing an empty bucket. The water of condensation flows through a pipe into the trap body. As the water rises in the trap, it floats the empty bucket, thus closing a valve in the center of the pot and preventing the water from running out. The trap blows steam out of the outlet only when first put into service; after the trap has been used once, there is sufficient water left in the body to hold the outlet valve closed. As the water continues to rise in the trap body, it finally overflows into the bucket until the weight of the bucket and the water it contains is sufficient to cause it to drop. This opens the outlet and the steam pressure then forces the water in the bucket out of the outlet until the buoyancy of the water outside the bucket is sufficient to raise the bucket again and thus to close the valve. The operation may then be repeated.



Bucket Trap.

116. Describe the construction and operation of a return trap.

A return trap is composed of a globe that performs the duty of a condenser and receiver. A live-steam inlet pipe fitted with a stop valve, a water outlet pipe fitted with a check valve, and a water inlet pipe fitted with a check valve are connected to a receiver that is set at the lowest ends of the return main. The trap is fitted with a rotary slide valve, a rocker with a loaded arm, two or more rods and a float. The operation is as follows: When a vacuum has been formed in the globe by the condensation of steam, water of condensation from the receiver will flow into the trap. When sufficient water runs into the globe, the float rises and causes the loaded end of the rocker-arm to descend, which pulls the rotary slide valve open and admits live steam at full boiler pressure. At this point, the globe is about full of water, and since the full boiler pressure is placed on the surface of the water in the globe and since the water in the globe is higher than that in the boiler, the water in the globe falls by gravity into the boiler. As the water drains from the globe, the float descends, the rocker-arm rises, and the rotary slide valve is closed. The trap is ready to receive another charge from the receiver as the steam condenses in the globe.

117. In speaking of the pipe system through which a boiler receives its water supply, what is meant by the external system and what by the internal system?

By the external system is meant the piping required to take the feedwater from its source of supply and deliver it at the boiler. By the internal system is meant the pipe leading from the outside of the boiler to the point of delivery.

118. When the water is to be lifted some distance, why should the suction pipe be as short and free from bends as possible?

Because, in general, it is very difficult to lift water to a greater height than 24 ft. at sea level, unless the pump is in excellent condition.

119. What common rules are to be observed regarding the discharge of feedwater into a boiler?

The common rule is that feedwater should never be discharged on the parts of the boiler exposed to the most intense heat, nor should it be delivered in a solid stream against a plate. It should be discharged in such a direction as to assist in the circulation.

COMBUSTION, FIRING, DRAFT

120. What is combustion?

Combustion is the rapid chemical combination of oxygen with either carbon or hydrogen, or both.

121. Name the leading varieties of coal?

Anthracite coal; **semi-anthracite** coal; **semi-bituminous** coal; and **bituminous** coal.

122. How may anthracite coal be distinguished from other coal?

It is rather hard to ignite and requires a strong draft to burn it. It is quite hard and shiny; in color it is a grayish or bluish black. It burns with almost no smoke.

123. How are the different sizes of anthracite coal usually named?

The different anthracite coals are named according to the **size** into which the lumps are broken, as **culm, rice, buckwheat, pea, chestnut, stove, egg, broken, steamboat** and **lump.**

124. How may semi-anthracite coal be distinguished from other coal?

It kindles more easily and burns more freely than the true anthracite coal. It crumbles readily and may be distinguished from anthracite coal by the fact that when just fractured it will **soil** the hand, while anthracite will not do so. It burns with very little smoke. The sizes are the same and are known by the same trade names as the corresponding sizes of anthracite coal.

125. How may semi-bituminous coal be distinguished from other coal?

Semi-bituminous coal differs from semi-anthracite coal only in having a smaller percentage of **fixed carbon** and more **volatile hydrocarbons.** Its physical properties are much the same, and it burns without the smoke and soot emitted by bituminous coal.

126. How may bituminous coal be distinguished from other coal?

Bituminous coal may be divided into three general classes: (1) **Caking** coals, which, when burned in the furnace, swell and fuse together, forming a spongy mass that may cover the whole surface of the grate. This spongy mass must be frequently broken up with the slice bar, in order to admit the air needed for its combustion; (2) **free burning coal,** which has no tendency to fuse together when burned; and (3) **cannel coal,** a grade of bituminous coal very rich in hydrocarbons. This grade is valuable for gas making, but is too costly to be used for the generation of steam.

127. Give a short explanation of the coking system of firing.

The coking system of firing is especially adapted to bituminous coals. The coal is first piled on the dead plate near the door and there allowed to coke, sometimes for 20 to 30 minutes. The coke is then pushed toward the bridge wall and distributed evenly over the fire. A new charge of coal is immediately heaped upon the dead plate.

128. Why are furnace doors or fire doors provided with special openings and dampers for opening and closing them?

This is done in order to admit air above the grates. The air is admitted in jets through the openings and mixes with the gases formed. The mixture passes to the rear over the bed of burning coke on the grate, where the temperature is high enough to insure ignition and complete combustion before the gases are chilled by contact with the cold surfaces of the boiler and tubes.

129. Give a short explanation of the spreading system of firing.

The spreading system of firing consists of covering the whole of the grate evenly with the fresh charge of coal. It is the system in most common use. Best results are obtained from the spreading system by firing light charges at frequent intervals. Covering the incandescent coke on the grate with a thick layer of fresh coal results in a lowering of the furnace temperature and, consequently, in a waste of heat. With bituminous coal, vast quantities of black smoke are produced. The spreading system is best adapted to anthracite in sizes larger than pea coal.

130. Give a short explanation of the alternate system of firing.

In the alternate system of firing, one side of the grate is spread with coal at one firing, and at the next firing the other side receives the charge. With this method the whole of the furnace is not cooled off at once by the fresh fuel. This method cannot be recommended as being the best for securing complete combustion. The gases from the freshly fired coal, instead of being passed over the bright bed of fuel on the other side of the furnace, are likely to pass directly to the chimney without being sufficiently heated to secure their ignition and complete combustion.

131. What are the causes of gas explosions in the furnace and how may they be avoided?

Explosions of the gases in the furnace, commonly referred to as **back drafts,** occur principally when small coal is used, and are the result of careless firing. When the smaller sizes of anthracite or bituminous coal are burned with the spreading system, and when a heavy charge is put into the furnace, an explosive mixture of air and hydrocarbon gas is obtained, which needs only a spark to ignite it. All danger of gas explosion is obviated if the firing is light or if some part of the fire is left uncovered when putting in fresh coal, thus igniting the hydrocarbons as quickly as they are distilled off.

132. Explain how a chimney produces a draft.

The hot gases that pass into the chimney are lighter, bulk for bulk, than the cool air outside the chimney. Naturally, then, the pressure in the chimney is a little less than the pressure of the outside air. Consequently, the outside air will flow into the chimney through the furnace.

133. How is artificial draft produced?

Artificial draft is produced by means of fan blowers or steam jets.

134. What is the difference between forced draft and induced draft?

In a forced draft installation, the air is forced into the ash-pit by either a fan blower or a steam jet; in an induced draft installation, a partial vacuum is created in the chimney or uptake, thereby causing the outside air to flow into the ash-pit.

135. What are some of the advantages of mechanical draft?

Blowers may be applied under almost all circumstances and their action is independent of the location of the plant; a blower may be automatically controlled to produce a uniform steam pressure; mechanical draft is entirely independent of climatic conditions.

136. How is the pressure due to draft measured?

The pressure due to draft is measured by means of a water gauge and is expressed in inches of water.

137. What is meant by volatile substances?

The substances driven off from the coal by moderate heat are called **volatile substances.**

138. What substance is left in coal after the hydrocarbons are driven off and of what elements is the substance chiefly composed?

The substance left in coal after the hydrocarbons are driven off is called **coke,** and is composed chiefly of carbon. This carbon is called the **fixed carbon** of the coal.

139. What is the igniting temperature of the fixed carbon?

It is estimated to be about 1,800° F.

140. What is the maximum temperature in the furnace?

It rarely exceeds 2,500° F. and is often several hundred degrees less.

141. State what conditions are essential for the economical combustion of coal.

There must be a supply of air sufficient to furnish the oxygen required for complete combustion. This air must be so distributed as to bring the oxygen into intimate contact with all parts of the fuel. The temperature must be high enough to bring about the combustion. With any of these essentials lacking, there will be incomplete combustion and a loss of heat.

142. What causes the formation of smoke?

The formation of smoke is caused by too low a temperature of the fire or by a distribution of the air that prevents oxygen from reaching the carbon before it is cooled by contact with the boiler plates. Heavy firing is one of the most common causes of smoke production. With properly constructed furnaces, good draft, and careful management, smoke prevention or alleviation is possible.

143. What is the effect of moisture on combustion?

All moisture that enters the furnace with the fuel must be evaporated at the expense of the heat developed by the combustion of the coal; the vapor thus formed passes out of the chimney at a temperature seldom less than 400 degrees. The moisture entering the furnace at a low temperature and leaving at a high temperature, 1,000 B.t.u. or more are lost for each pound of moisture in the coal. Therefore, coal should be stored dry.

144. Why is it advantageous to wet bituminous coal in some cases?

Because when wet, especially if the coal is fine, it cokes better and there is less waste from coal falling into the ash-pit. Wetting is only recommended for bituminous slack and anthracite culm, and should be as moderate as will secure the results desired.

145. What conditions are necessary for the complete combustion of coal and prevention of smoke?

For the complete combustion of coal and the prevention of smoke a sufficient and well distributed air supply is necessary. Without the proper distribution of the air supply, the high temperature necessary for complete combustion cannot be maintained.

146. What are the advantages of introducing air below the grate?

The air, in rising through the fuel bed, becomes highly heated. If a clean, even fire is maintained, the air supply is well distributed and comes in intimate contact with the gases almost as soon as they are formed; the air and gases are thus thoroughly mixed in the vicinity of the hottest part of the furnace and complete combustion follows. The danger of chilling the boiler plates by a current of cold air is less than when the air is admitted at any point above the grates.

147. State why air is sometimes introduced above the grate and give a simple method of so introducing it.

In a great many cases it is difficult to regulate the fire so carefully as to secure a proper supply of air through the grates. The quantity of fuel on the grate may also make it very difficult to keep a clean, open fire that will permit the steady supply of air demanded; it is therefore often essential that at least a part of the air required to burn the gases be supplied through openings above the grate. A simple method of supplying air above the grate is to provide the doors with special openings that serve to divide the entering current of air and distribute it over a considerable part of the grate. Methods for supplying air at the sides of the furnace and at the bridge wall have also been devised.

148. What is the object of firebrick arches?

Many locomotive boilers are fitted with **firebrick arches** that extend from the tube sheet towards the door and force the gases to take a path, first toward the door and then back above the arch to the tubes. The arch becomes highly heated, thus preventing the cooling of the gases before they become mixed with the air, and the path of the gases is lengthened sufficiently to enable them to burn before entering the tubes. It also increases the life of the tubes by preventing the entrance of large volumes of cold air when the door is opened, and thus aids in maintaining a more even temperature. Examples of modifications of the principle of the firebrick arch are seen in some of the automatic stokers and in the furnaces of such boilers as the Stirling water-tube boiler.

149. Is the use of steam or water under the grate beneficial?

It is beneficial in some cases. With coals that tend to clinker badly and to stick to the grates, the effect of steam under the grate is to prevent the clinkering to a considerable extent; this enables the fireman to keep the grate cleaner. Steam also prevents the destruction of the grate, and permits of a better distribution of air and more complete and economical combustion.

150. Does the use of steam under the grate result in a gain or loss of heat?

There are several features that may cause the use of steam under the grate to result in an actual loss of heat. The steam enters the ash-pit at a temperature seldom above 212° F., and passes into the chimney at the temperature of the flue gases, which is rarely below 400° F. It thus carries more heat into the chimney than it introduces into the furnace.

151. In order to secure an economical combustion what rules would you observe?

(1) Fire light and often. (2) Keep the fire as thin as circumstances will permit. (3) Keep the fire clean. (4) Keep the spaces between the grate bars clean. (5 Keep the ash-pit clear. (6) When using bituminous coal, use the coking firing system, if possible. (7) Regulate the draft so that it will be strongest when a fresh charge of coal is put into the furnace. (8) Do not let the fire burn out in spots. (9) Do not let the fire burn too long before charging. (10) If possible, fire at regular intervals and in regular charges.

152. If the temperature of the gases escaping up the chimney is too high, what is most likely to be the cause?

If the temperature of the escaping gases is in excess of 500° F., it indicates a serious loss of heat. The high temperature may be due either to insufficient heating surface, inefficient heating surface, or poor water circulation. Some heat is lost by radiation from the boiler itself and some from the setting and connections.

153. How can the heat losses be reduced?

In general, the trouble is that the efficiency of the heating surface has become impaired by reason of the collection of soot and condensible tarry vapors on the fire side and the deposits of scale on the water side. The remedy is to clean the surfaces and, thereafter, to clean them at such intervals as will keep them in a state of high efficiency. If the heat losses are due to poor circulation, it is difficult to state just exactly what should be done to improve it, since boilers vary so much in design. In horizontal return-tubular boilers, the trouble is often due to the tubes being packed too close together. Taking out one or two vertical rows has often resulted in a decided improvement in the circulation. There is no simple remedy for loss of heat due to an insufficiency of heating surface. About the only thing that can be done to make the plant more economical is to install more boilers, or perhaps a device for heating the feedwater by waste gases may be placed in the path of these gases before they reach the chimney. The heat lost by radiation from the boiler itself, and from the setting and connections, is minimized by covering the exposed parts by some good non-conducting material. In externally fired boilers, the brickwork setting is often made double; that is, there are two distinct walls separated by an air space. This answers very well when the setting is built in such a manner that the air within the air space cannot escape.

PROPORTIONS OF BOILER PARTS

154. What is the heating surface of a boiler?

The heating surface of a boiler is that part of the surface of the plates and flues or tubes that comes in contact with flame or hot gases on one side and water on the other side. With internally fired fire-tube boilers, the heating surface includes the interior surface of the furnace above the grates, and in case the boiler has an internal combustion chamber, the surface of this as well.

155. What is the ratio between the heating surface and the grate surface?

In practice, the ratio between the heating and grate surface varies with the type of fuel and the rate of combustion. But the average values coming within the limits of successful practice are 25 to 50 sq. ft. of heating surface per sq. ft. of grate surface in horizontal return-tubular boilers; 35 to 65 sq. ft. in water-tube boilers; 25 to 40 sq. ft. in marine fire-tube boilers; 35 to 40 sq. ft. in marine water-tube boilers; and 50 to 90 sq. ft. in locomotive boilers.

156. How can the grate area necessary for a boiler be found? Give an example.

The grate area of a boiler depends on the rate of combustion, the evaporation per pound of fuel, and the total weight of steam to be generated per hour. The grate area necessary can be found by the following method of calculation: Divide the number of pounds of steam the boiler is to generate per hour by the product of the number of pounds of coal burned per square foot of grate per hour and the number of pounds of water evaporated per pound of coal.

Example: The number of pounds of steam the boiler is to generate per hour is 3456; the number of pounds of coal burned per sq. ft. of grate per hour is 16; and the number of pounds of water evaporated per pound of coal is 9. Then the necessary grate surface must be: $16 \times 9 = 144$; $3456 \div 144 = 24$ sq. ft.

157. What is the ratio between the cross-sectional area of the tubes and the grate surface?

Average practice is to make the cross-sectional area of the tubes or flues equal to $\frac{1}{10}$ to $\frac{1}{9}$ of the grate surface for anthracite coal, and from $\frac{1}{7}$ to $\frac{1}{4}$ of the grate surface for bituminous coal.

158. What is the ratio between the steam space and water space in a boiler?

As ordinarily designed, from $\frac{1}{4}$ to $\frac{1}{3}$ the cubic contents of a horizontal fire-tube boiler is steam space and the remainder water space; but the steam space required by a given boiler depends on the purpose for which the steam is required.

159. (a) What is the cause of water-hammer in pipes? (b) Is water-hammer disastrous to piping?

(a) Water-hammer is caused by large or small bodies of condensed steam, thrown violently forward by the inrushing steam, due to opening a valve too quickly. (b) Yes. The heavy blow due to the momentum of the body of condensed steam moving with a high velocity is likely to cause leaking of the joints, or even breaking of the pipes.

160. Why are horizontal return-tubular boilers usually set lower at the rear than in front?

The rear end is set a trifle lower than the front end, so that the mud and sediment will tend to gather near the blow-off pipe.

161. Why is a circular chimney flue superior to a square one of the same area?

Because the inside surface of a circular chimney offers less resistance to the passage of the gases, and there is not the likelihood that eddies will be formed.

162. What is meant by vaporization?

The process of changing liquids into vapors by means of heat.

163. What is meant by the horsepower of a boiler?

The horsepower of a boiler is a measure of its capacity for generating steam.

164. What is the ratio of heating surface to horsepower, under ordinary boiler conditions?

The ratio of heating surface to horsepower is as follows:

Water-tube boilers 10 to 12 sq. ft. of heating surface per horsepower;

Return-tubular boilers 12 to 16 sq. ft. of heating surface per horsepower;

Locomotive boilers (stationary practice) 12 to 14 sq. ft. of heating surface per horsepower;

Vertical boilers 11 to 20 sq. ft. of heating surface per horsepower. (This method of rating boilers is, of course, indefinite; boilers with the same heating surface and of the same type, under different circumstances, generate very different quantities of steam. This method, however, is used by some boilermakers.)

BOILER MANAGEMENT

165. What precaution should be taken before filling a boiler?

Before filling a boiler it should be carefully examined internally, to see that no tools, lamps, or other foreign matter have been allowed to remain. Particular care must be taken that no oil is left on any of the internal surfaces. The presence of oil would tend to prevent the water from coming in contact with the metal, which condition is liable to lead to an overheating of the parts exposed to the fire.

166. Describe your course of action in closing a boiler preparatory to filling.

I would see that the gaskets are in good condition and that the surfaces with which such gaskets come in contact are clean; I would place a mixture of cylinder oil and graphite on the outer surface of the gaskets so that they may be removed without tearing; I would then carefully replace and properly secure all manhole and handhole plates; I would close the blow-off valve and proceed wtih the filling of the boiler, leaving the **top gauge-cock open** to allow the contained air to escape.

167. How high should the water be run up in a boiler before starting a fire?

The water should be run up high enough to cover all parts of the boiler that are subject to the action of the fire and hot gases on the outside.

168. What precautions should be taken before starting a fire under a boiler?

After the boiler has been filled to the proper level the attendant should see that the water column and connections are clear and free and that all valves in the connections and gauge-glass are open; he should also see that the gauge-cocks are in good working order and make sure that the pump, or injector, used for feeding the boiler, is ready to start when required. In general, he should see that everything is in readiness.

169. Why should the stress on the stop-valve spindle be relieved before steam is raised in a boiler?

If this were not done, the unequal expansion of the parts during the raising of the steam would tend to unduly strain some of the weaker parts, and the valve would be difficult to open.

170. Describe the course of action in starting a fire under a boiler.

It is usual to cover the grates with a layer of coal first, and then add the wood, on top of which may be thrown oily waste or other combustible material that may be at hand. To start the fire, light the waste or other easily ignited material and open the damper and ash-pit doors to produce draft. Then close the furnace doors. After the wood has been well started, spread it evenly over the grates and add a fine sprinkling of coal, until this in turn begins to glow, when more coal may be added and the fire occasionally leveled until the proper thickness of fire has been obtained. If the chimney refuses to draw, the draft can generally be started by building a small fire in the base of the chimney.

171. Give a reason why the fire should not be forced when getting up steam?

By forcing the fire, the plates and tubes that are nearest the fire suffer extreme expansion, while those parts that are remote from the fire are still cold; under such conditions the seams and rivets, and also the tube ends, are liable to be severely strained, and, possibly, permanently injured. It is not desirable to raise steam in any boiler in less than from 2 to 4 hours, according to the size, from the time the fire is first started.

172. After the pressure at which a boiler is to run has been reached, what should be done before cutting it into service?

All the valves and cocks should be tried under pressure. The safety valve should be raised and its action noted; the water column should be blown out and the gauge-cocks tested; the feeding apparatus should be tried; and it should be noted particularly if the check-valves seat properly and whether the valve in the feedpipe is open. All the accessible parts should be examined for leaks. Everything proving to be in good order, the boiler may be cut into service.

173. **Describe the course of action in cutting a boiler into service.**

The stop-valve, and in fact any valve that is subjected to high pressure, should be opened very slowly to prevent too sudden a change in the temperature and resulting expansion of the piping through which the steam flows, and to prevent **water-hammer.** The steam-pipe drain should be kept open until the pipe is thoroughly warmed up, to prevent the accumulation of water. In plants with many boilers and long steam mains, several hours should be allowed to thoroughly warm all pipes by a slow circulation of the steam, and not until then should the main stop-valve be fully opened.

174. **What precaution must be observed before connecting the different boilers of a battery to the same steam main?**

The pressures in the different boilers must be equalized within a variation of, say, 2 pounds before an attempt is made to connect them. This must be done to prevent a sudden rush of steam from one boiler into another.

175. **In plants where there are duplicate sets of boilers, what method would you recommend for changing over from one set to another?**

Start fires and raise steam in the boilers that are to be cut into service. Allow the pressure to rise in all to within 5 pounds of that which is carried on the boilers in operation. When a difference of 5 pounds is reached, change over. To do this, open (very slowly) the stop-valve on the boiler to be cut in and, then, close the stop-valve on the boiler to be cut out. The boilers having been changed over it will be in order to change over all appliances, such as the feed apparatus, etc. To do this, the valves must be closed on the boilers that have been cut out and opened on the set that has been cut in.

176. **When boilers are to be cut into service, why should the pressure in them be less than that in the boilers already in service?**

Because of the fact that the water of condensation at the dead end of the steam pipe will flow into the boilers to be cut in when the stop-valves are opened, instead of rushing toward the engine, as it would otherwise do.

177. **(a) After a boiler has been cut out of service, would you empty it immediately? (b) Why?**

(a) Unless existing conditions made it absolutely necessary, I would not empty the boiler immediately after being cut out of service. (b) The rapid contraction of the parts would be detrimental to the life of the boiler. Furthermore, if the boiler with its contained water, is allowed to cool down gradually, **the sediment will not be baked hard.**

178. **When the boilers of a battery are supplied from one feed pump, how is an equal water level maintained in all of the boilers?**

The quantity of water admitted to each boiler is regulated by its feed stop-valve. When the water gets low in any boiler, its feed stop-valve is opened wider, thus permitting a greater quantity to enter in a given time, while at the same time the feed stop-valve on one or more of the other boilers in operation may be closed partially and thus direct the feedwater to the one most requiring it. Some boiler plants employ check-valves with an adjustable lift; in that case the feed is equalized generally by adjusting the lifts of the check-valves, the stop-valves being left open while running.

179. **Why should fires be cleaned rapidly?**

Because during cleaning a large volume of cold air enters the furnace and chills the metallic surfaces with which it comes in contact.

180. **Why should the boiler feed be stopped while cleaning the fires?**

In order to reduce the loss in pressure caused by the condition of the fire and the open furnace doors while cleaning. However, the water level should be run up as high as is safe before starting to clean the fires.

181. Why should the pressure in a boiler be kept as steady and uniform as possible?

Because with a steady steam pressure the stresses on the boiler are constant, and under a steady stress the deterioration of the metal is much less rapid than under varying stresses. Furthermore, whenever the steam pressure is down, the furnace temperature is low at the same time. In consequence of this, large quantities of volatile matter in the coal often escape unconsumed and a serious loss of heat is thus caused.

182. What directions would you issue to your fireman, or observe yourself, in order to keep as uniform a steam pressure as possible?

Keep the fire of uniform thickness and allow no air holes in the bed of fuel. Fire evenly and regularly and not too much at a time. Keep the fire free from ashes and clinkers and as clean at the corners and sides as at the center. Keep the ash-pit clear. Do not clean the fires oftener than necessary. Manipulate the feeding apparatus so that just the necessary amount of water constantly enters the boiler.

183. If the steam pressure tends to rise above the standard, or highest desired pressure, what action would you take?

I would cover the fire with green fuel, close the damper, increase the feed, and, only as a last resort, I would open the furnace doors.

184. What is priming?

Priming is the same as **boiling over**; the water is carried into the steam pipe and thence to the engine, where considerable damage is liable to take place if it is not checked in time.

185. What are the causes for priming?

Insufficient boiler power; defective design of boiler; water level carried too high; irregular firing, or sudden opening of stop-valves; a small steam space.

186. How does priming usually manifest itself?

Priming manifests itself first by a peculiar clicking sound in the cylinder of the engine, due to the water being thrown against the heads. In cases of violent priming, the water will suddenly raise several inches in the boiler gauge glass, thus showing more water in the boiler than there really is.

187. How can priming be checked temporarily?

By checking the fires until the water is quiet.

188. How can priming be remedied?

The remedy will depend entirely on the cause. If the cause for priming is insufficient boiler power, the best remedy is to increase the size of boiler plant. A small steam space, which is one of the causes for priming, can be cured by the addition of a steam drum. Sometimes the top row of tubes can be taken out to advantage, which permits a lower water level. In many cases of priming a lower water level should be carried, the firing should be regular and too high a rate of evaporation should not be allowed. Stop-valves should not be opened suddenly.

189. (a) What is foaming; (b) what is the cause for foaming; (c) how is foaming detected; (d) how is foaming remedied?

(a) In cases of foaming the water in the boiler foams and froths at the surface; (b) the cause for foaming is dirty or greasy water in the boiler; (c) it is visible in the gauge glass; (d) the first thing to do in case of foaming is to quiet the water by checking the outrush of steam, either by slowing the engine down or checking the fire, or by both. The surface blow-off should be used in order to get rid of the dirty water. If no surface blow-off is fitted, the bottom blow-off may be used.

190. Does a boiler usually prime and foam simultaneously?

No. A boiler may prime and foam at the same time, but a foaming boiler does not always prime.

191. When shutting down for the night, what course of action should be taken regarding the water in the boiler?

The boiler should be filled to the top of the glass, so as to provide for posssible leaks and to admit of blowing out a portion before raising steam in the morning.

192. When shutting down for the night, what precau-

tion should be taken to prevent the steam pressure from rising during the night to a dangerous extent?

The fires may be banked so that there will be about enough steam to finish the day's run, thus shutting down under a reduced pressure. The fires should be shoved to the back of the grate and well covered with green fuel, leaving the front part of the grate bare. With the fires properly banked, the steam worked off and the damper shut, the possibility of the pressure rising during the night will cease to exist.

193. **In shutting down for the night, what valves should be closed?**

All steam stop-valves, feed stop-valves and the valves at the top and bottom of the gauge glass, should be shut off to prevent the loss of water.

194. **Why is a damper made so as not to close quite tight when shut to the full extent of its travel?**

Because sufficient opening must be left to permit the gases from the banked fire to escape up the chimney: otherwise there is danger of ignition of the accumulated gas, causing an explosion sufficient in force to at least wreck the boiler setting.

195. **Describe your course of action before opening the stop-valve for the day's run.**

When entering the boiler room in the morning, the first thing to which to give attention is the quantity of water in the boiler. The gauge glass and the gauge-cocks should be tried and the water level noted. If found not too low, the banked fires may be pulled down and allowed to come up slowly, the damper regulator, if one is fitted, in the meantime having been connected. Before the pressure begins to rise, the blow-off cocks should be opened and the boilers blown down about 3 or 4 inches, as shown in the gauge glass, so that any impurities that have settled during the night may be blown out. Next, all the valves, except the stop-valves, which were shut the night before should be opened and tried to see that they are free and in good working order. After the feeding apparatus has been tried and found in good order and everything is ready for a start, the stop-valve may be opened slowly.

196. Explain the purpose of the bottom blow-off and that of the surface blow-off.

The purpose of the bottom blow-off is to make possible the emptying of the boiler when necessary and of discharging the loose mud and sediment that collects from the feedwater. The surface blow-off serves to remove floating impurities that would finally settle and fall to the bottom of the boiler if not removed.

197. If the water in the boiler is discovered to be low, what should be done?

Quickly cover the fire with ashes, or, if they are not at hand, with fresh coal. Do not turn on the feed and do not tamper with the safety-valve or any other steam outlet. The fire may be drawn as soon as it can be done without increasing the heat. The boiler should then be carefully examined.

198. What instructions would you issue to your fireman, or observe yourself, regarding the blowing off of boilers?

When blowing off, the steam pressure should not be over 20 pounds. The boiler should be emptied at least every two weeks and filled up a-fresh. Blow out a few inches every day. A surface blow-off should be opened for a short time at frequent intervals. Examine the blow-off cock and check-valve every time the boiler is filled.

199. (a) Should a hot boiler be filled with cold water? (b) Why?

(a) No. (b) The practice of filling a hot boiler with cold water causes leaks and fractures and sometimes explosions.

200. What attention should the water-gauge and gauge-cocks receive and why?

The water-gauge and gauge-cocks should be kept clean and should be in constant use. The water gauges should be blown out frequently and the glasses kept clean. An obstructed gauge shows a false water level which is often the cause of serious trouble and sometimes results in an explosion.

201. What attention should be given a boiler regarding sediment and incrustation or scale?

Scale and sediment should be removed frequently. In tubular boilers particularly, the handhole or manhole should be frequently opened and the sediment removed from the portion of the plate over the furnace. In general, care should be taken to keep the boiler as free as possible from incrustation.

202. What attention should be given the exterior of a boiler?

Care should be taken that no water comes in contact with the exterior of the boiler, either from leaky joints or from other sources. Dampness in the setting or in the covering of the boiler should be avoided. Dampness leads to external corrosion.

203. What attention should be given fusible plugs?

Fusible plugs should be examined when the boiler is cleaned and scraped clean on both sides; otherwise they are liable to prove worthless.

204. What attention would you give the boiler brickwork?

I would see that the furnace, combustion chamber, and smoke flue are tight. The admission of air through the brickwork of the setting is the source of considerable loss.

205. What causes corrosion in boilers and how may it be prevented?

Corrosion is caused by corrosive impurities in the feed water; also by the galvanic action which is set up when brass or copper and iron come in contact in the presence of water. To prevent corrosion, the feedwater should be as free as possible from corrosive impurities. If bad water must be used, the impurities must be neutralized by adding alkaline substances, such as caustic soda or soda ash. When the corrosion is due to a galvanic action, it may be prevented by attaching zinc slabs to the boiler stays. It is supposed that zinc in connection with the iron of the plates keeps up a feeble opposed galvanic action, and that the hydrogen liberated at the surface of a plate by this action prevents incrustation from adhering to it. About 1 square inch of zinc surface should be supplied for every 50 pounds of water contained in the boiler.

206. How may unused boilers be kept in good condition?

Unused boilers may be kept in good condition by filling them full of water in which a quantity of common washing soda has been placed. Another method is to empty the boiler, dry it thoroughly, place trays of quick-lime in the bottom, and seal as nearly air-tight as possible.

207. Define corrosion.

Corrosion is the eating away or wasting of the boiler plates by the chemical action of impure water.

208. What is meant by uniform corrosion?

In cases of uniform corrosion, large areas of plate are attacked and eaten away. There is no sharp line of division between the corroded part and the sound plate, and oftentimes the only way of detecting the corrosion is to drill a hole through the suspected plate and thus ascertain its thickness.

209. What is pitting or honeycombing?

It is a form of corrosion which is readily perceived. The plates are in spots indented with holes and cavities from 1/32 to 1/4 inch deep.

210. What would you do upon the first appearance of pitting?

I would thoroughly clean the surface affected and give it a good coating of thick paint made of red lead and boiled linseed oil. I would give this treatment from time to time to insure protection to the metal.

211. What is grooving and how is it caused?

Grooving is a form of corrosion. It is generally caused by the buckling action of the plates when under pressure. The ordinary lap joint of a boiler distorts the shell slightly from a truly clyindrical form, and the steam pressure tends to bend the plates at the joint. This bending action is liable to start a small crack along the lap, which, being acted on by the corrosive agents in the water, soon deepens into a groove. The mark made along the seam by sharp calking tools, when used by careless workmen, is almost certain to lead to grooving.

212. What are some of the causes of external corrosion of fire-tube boilers?

Some of the causes of external corrosion are dampness, exposure to weather, leakage from joints, moisture arising from the blow-off, etc. When leakage ocurs in a joint that is hidden by the brickwork setting, the plates may be corroded very seriously without being discovered.

213. What causes external corrosion of water-tube boilers and how may it be prevented?

External corrosion of water-tube boilers is caused by the **combined** action of leakage and the gases of combustion. This corrosion usually extends from 4 to 8 inches from the headers. To prevent such corrosion, leaks should be prevented or attended to immediately, as the gases of combustion are harmless, unless acting in conjunction with water or dampness, or unless the coal is rich in sulphur.

214. In case it is doubtful which tube in a water-tube boiler is leaking, what would you do to stop the leak?

If a leaking tube cannot be exactly located I would expand all the tubes in that section so as to make sure of expanding the right one.

215. How often should boilers be cleaned both internally and externally?

Externally about twice a month; internally about once every two or three months, or oftener if necessary. The period of time that a boiler may be continued in service depends on the number of boilers in the plant, the nature of water used, whether or not the plant is shut down on Sundays and holidays, and the general local conditions governing the plant.

216. Describe the method of procedure when a boiler is to be cut out of service preparatory to a thorough overhauling.

After the boiler to be overhauled has been cut out of service by closing all necessary valves, the fires should be allowed to die out gradually. The boiler should stand for at least 24 hours before commencing cleaning operations and repairs. When the boiler has cooled sufficiently, the ashes should be pulled from the grates and the ash-pit. The furnace, the setting, the external surface of the boiler, and the tubes should be thoroughly cleaned. The boiler should next be emptied, the manhole plates and handhole plates should be taken off and the internal surfaces cleaned. The hose should now be introduced and the boiler thoroughly washed out. The boiler and setting should then be examined and all defective parts repaired or replaced.

217. When inspecting the interior of a boiler, what defects should be looked for?

The internal surface of the plates should be examined at the water line for pitting and at the junction of the plates in the seams for grooving. The condition of the stays and braces and whether they are tight should be noted. The interior surfaces should also be examined with reference to scale and mud.

218. Describe the method of procedure when inspecting the exterior of a boiler and its brickwork for a thorough overhauling.

After the external surfaces of the boiler, the combustion chamber, the back connections, and the setting in general, have been cleaned, the grate bars should be examined and any that may be defective should be removed, replacing them with new bars. The furnace brickwork should next be examined. Where bricks have been knocked out or where walls bulge or are cracked, repairs should be made. All attachments, such as stop-valves, check-valves, safety valves, water column and gauges, blow-off cocks, etc., should be carefully examined and put in good working order. In cases where a repair is not feasible, a new part should replace the old one.

219. In the water-tube type of boiler, how are the external surfaces of the tubes cleaned?

The external surfaces of water-tubes are cleaned by using a steam hose to blow off the soot that lies on the upper surfaces. When the soot is rather sticky, the steam hose is not very effective, and a special tool must be used. This tool is made from a piece of ½ inch square iron bent so as to pass down between the vertical rows of tubes, and then bent again so that it lies upon the tube to be cleaned. By running this tool back and forth a few times over each tube the dirt can be effectively scraped off.

220. In fire tube boilers, how are the internal surfaces of the tubes cleaned?

A steam hose is used for blowing the soot toward the back into the combustion chamber. Scrapers and wire brushes are also used for cleaning fire tubes. These scrapers and wire brushes are usually affixed to a pipe of small size, which is made up of parts coupled together to meet the requirements of space and ease of handling.

221. What methods of preventing the extension of internal corrosion and pitting may be employed?

To prevent the extension of internal corrosion and pitting, where they have just commenced, apply a good coating of paint made of red lead and boiled linseed oil. The metal should first be cleaned thoroughly and the paint applied as thickly as it can be readily applied with a brush. The paint should be allowed to dry hard before filling the boiler. The paint should be applied as frequently as may be necessary. Another method for the protection of the internal surfaces of a boiler is to apply a coating of **graphite** mixed in boiled linseed oil and as stiff as can be applied with a brush.

222. Describe the method of procedure in washing out water-tube boilers.

The only thorough way of washing a water-tube boiler is to introduce the hose nozzle in each and every tube, and, commencing at the top, to wash out the contents, which fall into the mud-drum. Every water-tube boiler should be so treated at least once every 12 months. For an ordinary washing, which should be done every month or 6 weeks, remove the manhole plates and flood the interior of the steam drums with water under pressure, through a hose nozzle. In order that the effect may be as far reaching as possible, continue the flooding for about 1 hour. The mud drums should also be washed out thoroughly.

223. What parts of a horizontal water-tube boiler require the most frequent attention? Why?

The tubes. They will occasionally leak at the front and back ends where they are expanded into the headers. Sometimes, owing to small unsuspected leaks around the expanded portion, the external surface of the tube for 3 or 4 inches from the header becomes corroded to such an extent that small pinholes may appear. Again, those portions of the tubes that are directly over the fire may give out, small holes appearing, which are due to pitting on the internal surfaces. Sometimes a tube will give out at the weld, owing to imperfections in the workmanship. This is the most dangerous incident probable with water-tube boilers, but considering the large number of tubes in use, it very rarely occurs.

224. When a leak appears around the expanded portion of a tube, describe in detail how to stop it.

Apply a roller tube expander. When expanding an old tube, care should be taken not to expand any more than just enough. When the rollers in the expander make a clear and well-defined track in the tube it is time to stop. The expander should be oiled while using.

225. Why are fire doors of boilers fitted with a baffle plate, or lining? Why is the plate perforated?

The perforated baffle plate, or lining, serves the combined purpose of protecting the door from the heat radiated from the fire and of dividing the entering current of air into a large number of small jets that are considerably heated in their passage over the surface of the plate, and are then distributed to the fire through the perforations and around the edges of the plate.

226. Describe the method of withdrawing a boiler tube that has given out.

By means of a cutting tool, known as a **ripper,** a slit is cut about 1/8 inch wide and extending about 1 inch beyond the inside of the sheet. The end of the tube can then be readily squeezed together so that the tube will pass through the hole. Care must be taken not to injure the tube-sheet or header.

227. If a boiler tube gives out at a time when neither repairs nor renewal are possible, describe what to do in such an emergency.

Place stoppers in the tube. A home-made stopper consists of two tapering pine plugs having a central hole through which a rod made of 1/2 inch round iron is passed. This rod is provided with nuts and washers at each end, by means of which the plugs can be drawn home. The objection to this tube stopper is that a man must enter the back connection in order to place the plug in the rear end, and in order to put the nut and washer on the rod. There are stoppers on the market that can readily be applied without stopping the operation of the boiler.

228. How may leaky seams and rivets in fire tube boilers be made tight?

Leaky seams, also leaks around rivet heads, may be made tight by calking. Repeated light blows of the hammer on the calking tool are more effectual than heavy blows; in fact, heavy blows are liable to cause the seams to leak worse than at first.

229. How may a crack in any of the boiler plates be repaired?

A crack may be repaired by drilling a small hole at each end of the crack, to prevent the crack from extending further, calking the crack, and putting a patch over it. If the crack should be extensive, the part of the plate containing it should be cut out and a patch put on.

230. Describe the two kinds of patches used in repairing boilers.

The two kinds of patches used are soft patches and hard patches. A soft patch is one that is put on with bolts and nuts or with tap bolts. Red lead putty is used between the plates to make a joint that will be water-tight under pressure. Soft patches should never be used on plates that are subjected to the direct heat of the fire. Hard patches are secured with rivets and are the only kind of patches which should be used on boiler work. In putting patches on plates that are directly over the fire, the affected part of the plate should be cut out before the patch is placed on. The place cut out should be as nearly circular as possible. In any case, no sharp corners should be left, because of the tendency of cracks to start at such places. All patches should be placed on the **inside** of the plate.

231. What is the cause of laminations or blisters in boiler plates and what repairs should be made in such cases?

Laminations are due to slag and other impurities in the metal, which in the process of rolling the plates become flattened out. The action of the fire on such particles forms a blister. If the laminated portion of the plate is small, a hard patch can be put on. If there are a number of laminations in the same plate, a new plate should be put in.

232. Describe the water column. How is it connected to the boiler?

The water column consists of a cast-iron standpipe tapped at the top and bottom for pipe connections to the boiler. The upper end communicates with the steam space of the boiler, and the lower end with the water space. The connections to the boiler should be made with a T on the top and a cross on the bottom, with the unused openings plugged with brass plugs. A drain pipe with a valve in it is provided for blowing out any sediment which may collect in the standpipe. For high-pressure boilers, valves should be placed in the pipes leading to the steam and water spaces of the boiler.

233. How should a water column and its connections be blown out?

Close the valve on the upper pipe and open the valve in the drain pipe. This blows out the lower pipe. Close the valve in the lower pipe and open the valve in the drain pipe. This blows out the upper pipe and standpipe.

234. Describe the high-and-low water alarm and its operation.

The device consists of two hollow floats suspended from bell-cranks inside the water column. To the short arm of each bell-crank is attached the valve stem of a small valve. These valves serve to put the steam space of the water column in communication with the alarm whistle. When the water is at its proper level, the lower float is pressed upward, which keeps the upper whistle valve closed. When the water becomes low, the float descends, thus opening the upper whistle valve and sounding the alarm. The high-water alarm float keeps the lower whistle valve closed by the weight of the float. When the water rises, the float is carried upward, the lower whistle valve is opened, and the alarm sounded. Low water alarms depending on the difference in expansion of different metals for actuating a whistle valve, or an electric bell, are also on the market.

235. Describe the hammer test.

Striking the plates, stays, and tubes with a hammer to determine their soundness, is called a hammer test. Sound plates and tubes when struck with a hammer emit a clear, bell-like ring, while those that are thin or defective give forth a dull sound, similar to that of a cracked piece of pottery. A broken stay gives a peculiar sound that cannot be described by words.

236. What is known as the hydrostatic test, and what are the points in favor of and against it?

Filling the boiler with water and applying a pressure by means of a pump or other device is known as the hydrostatic test. It is valuable only in showing leaks and for determining the ability of the boiler to withstand a prescribed pressure. It will not reveal weak places unless such places are so weak as not to be able to stand the required pressure. There is also danger of straining the plates beyond the elastic limit, and of permanently injuring a boiler which would have been safe at the working steam pressure. The insurance companies, in most cases, depend on the hammer test and ocular inspection.

237. When applying the hydrostatic test, what precaution is necessary? Why?

When applying the hydrostatic test, it is necessary to provide for the escape of air from the boiler while filling it with water. Some valve or cock, located as high as possible on the boiler, should be left open until the water is forced out in a solid stream. This precaution is necessary because should the boiler burst under pressure while still containing air, the parts, by reason of the expansion of the air, are liable to fly with great force. A boiler from which all air has escaped, if bursting under the hydrostatic test, will not do any serious damage.

238. When the intercommunication, between the boiler to be tested and those in operation, is closed off only by a valve, what precaution would be necessary before applying the hydrostatic test?

It will be necessary to place a **blank flange** between the valve and the boiler that is to be tested, thus completely isolating the boiler from those in operation. This is a measure of safety, which the valve alone is not capable of insuring.

239. **What is usually considered to be the safe working pressure of a boiler?**

Two thirds of the hydrostatic pressure under which the boiler was tested is usually considered to be the safe working pressure.

240. **What method is there for the testing of a boiler hydrostatically without the application of a pump?**

The boiler is filled full of cold water and a gentle fire is built in the furnace. As the temperature of the water rises, it expands and thus subjects the boiler to pressure. The temperature of the water should in no case be made to rise above 212° F.

241. **What causes boiler explosions?**

Either the boiler is not strong enough to carry its **ordinary working pressure,** because: (1) It is poorly designed. (2) The material or the workmanship may be poor. (3) The boiler may have become weakened by corrosion. (4) The boiler may have become weakened by careless or reckless management, such as letting cold water come in contact with hot plates; or:

The pressure rises **above the usual point** at which the safety valve is set, due to the sticking or overweighing of the safety valve.

In internally fired boilers, low water may cause an explosion.

242. **What rules should be observed to prevent boiler explosions?**

Have the boiler inspected or tested to determine its safe working pressure. Use all possible care to prevent internal and external corrosion. Do not strain the shell by subjecting it to great changes in temperature. Do not overload the safety valve, and do not let it become corroded fast to its seat. Do not allow the water to get very low. Do not open or close large stop-valves leading to the main steam pipe, suddenly. Do not try to use a boiler after it is worn out. Never allow a stop-valve to be placed between the safety valve and the boiler.

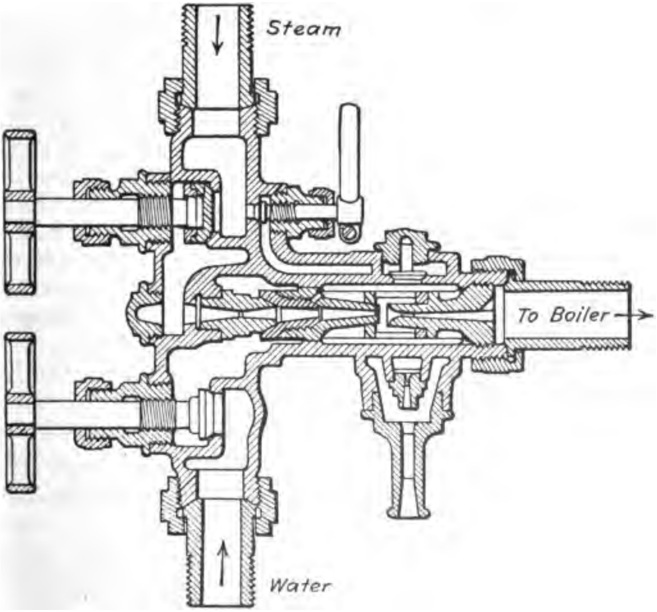
BOILER FEED APPARATUS

243. What different kinds of apparatus are used for feeding boilers?

Pumps of various kinds, **injectors** and **inspirators**, and the **gravity-feed** apparatus.

244. Describe the action of an injector.

The steam entering an injector and moving with an extremely high velocity first carries the air inside the injector with it and thus creates a partial vacuum, causing the water to flow into it. The steam then imparts a portion of its velocity to the water and gives it sufficient momentum to throw open the check-valves and enter the boiler.



Injector.

245. What happens if (a) the steam supply of an injector is too large, (b) too small, (c) water supply too large, (d) too small, or (e) too hot?

(a, d,e) If the steam supply is too large, or the water supply too small, or too hot, the steam will not all be condensed in the **combining tube** and, owing to its lightness, will not be carried into the boiler, but will flow into the overflow space and be discharged from the overflow nozzle. This escaping steam breaks the jet of water and stops the flow into the boiler, and serves to show that there is too much steam admitted in proportion to the water used. (b, c) If the steam supply is too small or the water supply too large, the velocity of the jet of water flowing from the nozzle is so small that its momentum is not sufficient to carry it into the discharge pipe against the pressure in the boiler, and the water is discharged through the overflow space and out of the overflow nozzle.

246. How does the steam pressure affect the temperature of the water an injector will deliver?

The temperature of the water delivered by an injector will increase as the capacity of the injector is cut down from its maximum to its minimum. Under high steam pressure, 140 pounds and upward, and while working at its maximum capacity, an injector may deliver water at about 135° F.; while if the injector is cut down to its minimum capacity, the water would be delivered atabout 250° F. Under ordinary working conditions the water is delivered at a temperature between 160° and 180° F. The temperature at which an injector will lift the feedwater **decreases** as the steam pressure under which the injector is working is **increased.** At low steam pressure, the injector may raise water at 125° or 130° F.; while at 140 pounds and upward it is not safe (with ordinary injectors) to have the water supply much above 110° F.

247. What effect has the steam pressure on the amount of water delivered by an injector?

Very little effect. If the supply and outlet water temperatures are both fixed, high steam pressure slightly increases the weight of water delivered per pound of steam used. Usually about 10 lb. of water are delivered per lb. of steam.

248. What is meant by the range of an injector?

The term range refers to the difference between the steam pressure at which the injector will start and the steam pressure at which it ceases to work.

249. What relation does the range of an injector bear to the distance that water can be lifted and to its temperature?

The range of an injector decreases with any increase in the distance that the water must be lifted, and also decreases with any increase in the temperature of the water supply. The steam pressure at which injectors of different makes will start varies somewhat, but the range between the starting and stopping pressures with different injectors is practically the same under the same conditions.

250. At what steam pressure do injectors usually start?

Most injectors will start on 25 pounds steam pressure, but some are made to start on 15 pounds.

251. Into what classes may injectors be divided and in what way do these classes differ?

Injectors may be divided into two general classes, the **non-lifting** and **lifting** injectors. They differ from each other in that the lifting class is capable of lifting the water from a level lower than its own, which the other class cannot do.

252. Where should non-lifting injectors be placed?

Non-lifting injectors are intended for use where there is a head of water available, therefore they must be placed below the water level of the supply tank, if one is used. When the water comes from a city main, the injector can be placed in almost any convenient position, close to the boiler.

253. What types of lifting injectors are there?

The **automatic** and the **positive** or **double-tube** injectors.

254. In what way do the positive, or double-tube injectors differ from the automatic injectors?

The automatic injectors will automatically start again in case the jet of water is broken by jarring or otherwise, and are simpler in construction than double-tube injectors. They are very generally used on stationary and portable boilers and traction engines. The positive, or double-tube injectors are provided with two sets of tubes, one set of which is used for lifting the water, while the other set forces the water, so delivered to it, into the boiler. They have a wider range than the automatic injectors and will handle a hotter feedwater supply. They will also lift water to a greater vertical height than the automatic injectors.

255. What is the distinguishing feature of the automatic injector?

The automatically closing **overflow valve** which is found in some form or other, in all automatic injectors.

256. What keeps the overflow valve closed while the water is running into the boiler?

The atmospheric pressure on top of it keeps it closed, there being a partial vacuum in the space inside.

257. Name some of the injectors in common use.

The Penberthy automatic injector; the Buffalo automatic injector; the Hancock inspirator; the Koerting universal double-tube injector; the Monitor lifting injector; etc.

258. Describe the exhaust steam injector.

Exhaust steam injectors make use of exhaust steam. Their principle of action is the same as that of the live-steam injector, from which they differ only in the relative proportions of the nozzles. Exhaust-steam injectors will not generally work against boiler pressures exceeding 75 pounds. It is necessary to furnish an exhaust injector with a live-steam connection in order that it may be used when the engine is not working. The live steam is throttled so that it will enter the injector at about the pressure of the exhaust steam, as this injector will not work when supplied with steam at full boiler pressure.

259. How would you determine the size of an injector needed to feed a boiler?

It is good practice to select a size of injector having a capacity per hour about one-half greater than the maximum evaporation of the boiler per hour.

260. When the maximum evaporation of a boiler is

not known, how would you estimate it in gallons per hour?

I would estimate it by the following rules: (1) For plain cylindrical boilers, multiply the product of the length and diameter in feet by 1.3 (2) For tubular boilers, multiply the product of the square of the diameter in feet and the length in feet by 1.9. (3) For water-tube boilers, multiply the heating surface in square feet by 0.8. (4) For boilers not covered by the foregoing rules, multiply the grate surface in square feet by .15. (5) If the coal consumption in pounds per hour is known, it may be taken as representing the number of gallons evaporated per hour.

261. In what position would you place an injector?

An injector must always be placed in the position recommended by the maker, for the reason that some injectors will work well only in one position.

262. What valves are necessary for the proper installation of an injector and where should they be placed?

There must be a stop-valve in the steam-supply to the injector, which should be placed as close to the injector as possible for convenience. When the water flows to the injector under pressure, a stop-valve in the water-supply pipe is a necessity. When the injector is lifting the water a stop-valve in the suction pipe is not absolutely needed, but it is advisable to supply it. A stop-valve and check-valve must be placed in the feed-delivery pipe, with the stop-valve next to the boiler.

263. How should the overflow of an injector be connected?

The overflow of an injector should never be connected directly to the overflow pipe, but a funnel should be placed on the overflow pipe so that the water can be seen. No valve should ever be placed in the overflow pipe of an injector. This, however, does not apply to the inspirator or to any other injector that has a hand-operated, separate overflow valve. In the inspirator, the overflow pipe is connected directly to the overflow, but the end of the pipe must be open to the air.

264. Would you place a foot-valve in the suction pipe, where the injector lifts water? Why?

No. It is desirable that the injector and pipe be self-draining when not in use. It is a good idea to place a strainer on the end of the suction pipe.

265. What directions would you give, or observe yourself, regarding the steam connection for an injector?

The steam for the injector must be taken from the highest part of the boiler, since it is essential that the injector be supplied with dry steam. An injector should always have an independent steam-supply pipe; therefore, under no consideration should the steam be taken from another steam pipe.

266. What directions would you give, or observe yourself, in connecting the steam pipe, suction pipe, and feed-delivery pipe to an injector?

The injector should always be so located that the steam pipe, suction pipe and feed-delivery pipe will be as straight and as short as possible. The suction pipe must be absolutely air-tight.

267. State some of the causes that prevent an injector from raising water and explain how to remedy the trouble.

(1) The suction pipe may be clogged up, which is the most frequent cause of an injector's not priming. In such case, blow steam back through the suction pipe to force out the obstruction. (2) There may be a leak, or leaks, in the suction pipe, in which case air enters and prevents the injector forming the vacuum required to raise the water. To test the suction pipe for air leaks, plug up the end and turn the full pressure of steam on the pipe. To get steam into the suction pipe, the overflow valve must be held to its seat in some convenient way, or the overflow must be closed tight in some manner. It is advisable to have the suction pipe full of water before the steam is turned on, since the presence of small leaks will be revealed better by water than by steam. (3) The water in the suction pipe may be too hot. If the water in the source of supply is too hot, cool it in any convenient

manner. If the water in the source of supply is cool, but very hot in the suction pipe, there is most likely a choked overflow. In such case, hold the overflow valve to its seat in some convenient manner, or plug the overflow and open the steam valve. The steam pressure will then force the hot water out of the suction pipe. Open the overflow as soon as this occurs. The cool water should then be raised easily. (4) There may be an obstruction in the lifting or combining tubes, or the openings from the tubes through which the steam and the water escape to the overflow may be clogged up with dirt or lime. In either case, a steam pressure instead of a vacuum will be formed in the suction pipe. The obstructions should be removed.

268. In some cases, an injector will lift water, but will not force it into the boiler; or it will force part of it into the boiler and the rest out of the overflow. State what causes the trouble and how it may be remedied.

The trouble may be due to one of the following causes: (1) The supply pipe, the suction pipe or the strainer may be partially choked, which prevents the injector from getting sufficient water to condense all of the steam supplied through the steam valve. The uncondensed steam decreases the vacuum in the combining tube, until finally the injector will **break.** In the case of a choked supply pipe, open the supply valve. In the case of a choked suction pipe, blow out the obstruction with steam. (2) There may be a slight leak in the suction pipe which will prevent the injector from lifting sufficient water to condense all the steam. This destroys the vacuum in the combining tube. The suction pipe should be tested and the leaks, when found, repaired. (3) The boiler check-valve may be "stuck shut." If completely closed, the injector may or may not continue to raise water and force it out of the overflow—it depends on the design of the injector. If the boiler check is partly open, the injector will force some of the water into the boiler and the remainder out of the overflow. In case the check-valve cannot be opened wide, water may be saved by throttling both steam and water until the overflow ceases or, at least, diminishes. The steam should be throttled at the valve in the boiler steam connection, not at the steam valve of the injector, as throttling tends to superheat the steam, and the injector will not work satisfactorily with superheated steam as with saturated steam. If a check-valve sticks, it can sometimes be made to work again by tapping **lightly** on the cap or on the bottom of the valve case. (4) There may be an obstruction in the delivery tube. Cotton waste, scale or coal in the delivery tube will cause a heavy waste of water from the overflow. To remedy this, the tube may have to be removed and cleaned. (5) There may be a leak in the overflow valve, which not only diminishes the capacity of the injector, but allows air to be drawn into the boiler. If the leak is sufficiently great, it will destroy the vacuum in the combining tube and prevent the injector from operating. A leaky overflow valve is indicated by the chattering of the boiler check on its seat. To remedy this defect, grind the valve on its seat until it forms a tight joint. (6) If the interior of the tubes is not perfectly smooth and of the proper bore, an injector will not operate properly. When the water used is very bad, the tubes lime up in course of time, and the capacity of the injector decreases until, finally, it refuses to work at all. This defect may be remedied by putting the tubes in a bath, consisting of one part of muriatic acid to 10 parts of water. The acid combines with the lime and forms a gas, and as long as there is lime to combine with, the acid will not attack the copper in the tubes. The tubes, therefore, should be removed from the bath as soon as the gas bubbles cease to be given off.

269. **What are the advantages of the injector as a boiler feeding apparatus?**

The advantages of the injector are its cheapness, as compared with a pump of equal capacity; it occupies but little space; the repair bills are low, owing to the absence of moving parts; no exhaust piping is required, as with a steam pump; it delivers hot water to the boiler.

270. **What are the disadvantages of the injector as a boiler feeding apparatus?**

The disadvantages are that it will not start with a steam pressure less than that for which it is designed, and that it will stand but little abuse, being poorly adapted for handling water containing grit or other matter liable to cut the nozzles.

271. Is there any economy derived from the use of an injector?

Yes. Although an injector uses more steam than a good steam pump, its operation insures the delivery of hot feedwater to the boiler, which has a marked effect upon the repair bills and tends to increase the life of the boiler.

272. What apparatus, other than the pump and injector, is there for feeding boilers?

The **gravity-feed** apparatus.

273. Why does the water in a gravity-feed apparatus run into the boiler?

The hydrostatic head of the water and the full boiler pressure on top of the water in the gravity-feed apparatus cause the water to run into the boiler.

274. Describe the gravity-feed apparatus used for the feeding of boilers.

The simplest form of gravity-feed apparatus consists of a closed vessel placed about 6 feet above the boiler and connected at the top by a steam pipe to the boiler, while at the bottom it connects to the feed pipe. A pipe also connects the closed vessel to the source of water supply. In operation, the vessel is first nearly filled with water, and steam from the boiler is then admitted on top of the water, thus submitting it to the full boiler pressure. Then, by reason of the vessel's being elevated above the boiler, there is sufficient hydrostatic head for the water to flow into the boiler. The water, being in direct contact with the live steam, is heated to a fairly high temperature. Whenever the vessel is empty, the steam is shut off and water run in again, after which the operation can be repeated. A more elaborate gravity-feed system uses a steam trap with an automatic refilling device, giving a fairly constant feed, which is adjustable to suit the demand. This system is the one almost invariably used to return the water of condensation from gravity steam-heating systems to the boiler. It is also sometimes used for feeding water coming from other sources.

275. What is the object of automatic feedwater regulation and why is it desirable?

The object of automatic feedwater regulation is to keep the water level in the boiler steady. It is desirable because it is conducive to a steady steam pressure and to economy in the use of fuel, and, incidentally tends to prevent the water from becoming low enough to be dangerous or high enough to be carried over to the engine.

FEEDWATER

276. Name some of the impurities most commonly found in feedwater.

The impurities most commonly found in feedwater are: carbonate of lime (lime stone or marble), sulphate of lime (plaster of Paris), and chloride of sodium (common salt).

277. What other troublesome substances does feedwater often contain?

Chloride of magnesium, organic matter, earthy matter, acids.

278. How is scale generally formed in a boiler?

The small solid particles of the impurities in the feedwater remain for a time suspended in the water. These particles will gradually settle on the internal surfaces of the boiler (a large part of them being carried by the circulation of the water to the most quiet part of the boiler) and form a scale.

279. What is the chief danger from the formation of scale in the boiler?

The chief dangers from a heavy scale are the danger of overheating the plates and tubes; the danger of hiding a dangerously corroded piece of plate or a defective rivet head that would otherwise be discovered, and also the danger of stopping up the feed pipe, the blow-off pipe, or the connections to the gauge glass.

280. How is scale generally removed?

A hard scale is generally removed by chipping it off with scaling hammers and scaling bars; soft scale can be largely removed during running by a periodic use of the bottom and surface blow-offs, and the remainder can usually be washed out and raked out when the boiler is blown out and opened.

281. Can incrustation or scale be removed by the use of chemicals?

When incrustation has once been formed, it cannot very readily be dissolved again by any chemicals, although some substances seem to soften and aid in detaching it. Of these, kerosene oil has met with much favor. Its action appears to be mechanical rather than chemical, the oil penetrating or soaking through the scale and softening and loosening it. Kerosene is somewhat useful in preventing the formation of scale. It seems that it envelops the particles of the scale-forming substances that float on the surface of the water for a little while, and prevents these particles from adhering firmly to one another, or to the metal when they finally settle. Some engineers claim that kerosene oil does harm as well as good, since it leaves the metal entirely unprotected and thus permits of pitting and corrosion.

282. **How may the scale-forming substances deposited on the internal surfaces of a boiler be prevented baking hard?**

In order to prevent the scale-forming substances from baking hard, it is advisable to let the boiler cool down slowly until entirely cold before blowing off. This cooling down process will generally take from 24 to 36 hours.

283. **Which is the worst of the impuritites found in feedwater and why?**

Chloride of magnesium is the worst of all, for while it is not dangerous as long as the water is cold, it makes the water corrosive when heated, and when present in large quantities, it becomes dangerously corrosive, attacking the metal of the boiler and rapidly eating it away.

284. **If the feedwater contains acid, how can corrosion be prevented? State what acids are found in feedwater.**

Water containing acid should be neutralized before it is used. The acids often present in feedwater are sulphuric acid, nitric acid, tannic acid and acetic acid. The most dangerous of the acids, attacking the metal and corroding it very rapidly, is sulphuric acid. The other acids, while not so violent in their actions, are also dangerous.

285. **How can incrustation best be prevented?**

It can best be prevented by purifying the feedwater before it enters the boiler, and can be prevented to some extent by a chemical treatment of the water in the boiler in case purification prior to the water's entering the boiler is not resorted to. When the water contains large quantities of substances that float on the surface, the surface blow-off should be used at frequent intervals.

286. What methods are generally used for purifying feedwater?

Feedwater may be purified by settlement, by filtration, by chemical means, and by heat.

287. Describe a method of purifying feedwater containing much matter in mechanical suspension.

One of the simplest methods for purifying feedwater containing much matter in mechanical suspension, is to provide a relatively large reservoir or tank, where the impurities can settle to the bottom. While this method is fairly satisfactory, as far as earthy matter is concerned, it will not clear the water of finely divided organic matter, which is usually lighter than the water and often so finely divided as to be almost dissolved in it.

288. Describe a method of purifying feedwater containing organic and earthy matter in mechanical suspension.

Organic and earthy matter in mechanical suspension is most satisfactorily removed by a filter, passing the water through layers of sand, gravel, hay, or equivalent substances, or through layers of cloth. Hay and cloth are of service especially where the feedwater contains oil or grease.

289. Describe the hay filter used in condensing plants.

A hay filter is extremely simple, consisting of a wooden tank open on top and divided into two compartments by a partition perforated near the bottom. The one compartment is filled with hay, the feedwater from the hot well being discharged into the top of it. The hay quite effectually removes the oil and grease from the water, which is taken from the second compartment by the feed-pump or injector. The hay will have to be removed and replaced quite frequently.

290. Describe a cloth filter used in condensing plants.

There are a number of cloth filters used in condensing plants. Most of them consist of a vessel divided by perforated plates, or light circular sections of open latticework, or filtering diaphragms, covered by **linen terry,** a coarsely woven cloth popularly known as **Turkish toweling.** The feedwater is admitted to the vessel and cannot reach the outlet except by passing through the filtering material. The floating impurities rise into a scum chamber whence they are removed periodically by opening a blow-off. The heavier impurities settle into a pocket which is provided with a blow-off cock. The foreign matter filtered from the water accumulates on the filtering material, and in course of time offers considerable resistance to the passage of the water. This resistance is shown by the difference in reading of two pressure gauges. When this difference amounts to 3 pounds, the filter is in need of cleaning. The filter may be cleaned by boiling it out with soda and blowing the matter out through the blow-off. If boiling out fails to clean the filter, the filtering material must be removed and new material substituted.

291. **What particular impurities is the filter supposed to remove?**

A filter will remove impurities in mechanical suspension, such as oil and grease, and earthy matter.

292. **What impurities cannot be removed by a filter? How should feedwater containing such impurities be treated?**

Impurities **dissolved** in the water cannot be removed by a filter. A chemical treatment or treatments of the water will render the scale-forming substances and corrosive acids harmless. These treatments may be applied either before or after the water enters the boiler, preferably before.

293. **How should water containing only carbonate of lime be treated?**

It may be treated with slaked quick-lime, using 28 grains of dry lime for every 50 grains of carbonate of lime present in the water, the quick-lime precipitating the carbonate of lime and being itself transformed into an insoluble carbonate of lime during the process. Water containing carbonate of lime may also be treated with caustic soda, which precipitates the carbonate of lime and leaves carbonate of soda, which is comparatively harmless. For every 100 grains of carbonate of lime 80 grains of commercial caustic soda should be added.

294. What is the danger in treating water, containing carbonate of lime, with sal ammoniac?

While sal ammoniac will precipitate carbonate of lime, there is the danger of the formation of hydrochloric acid, which will attack the boiler.

295. How should water containing both, carbonate of lime and sulphate of lime, be treated?

The most available chemicals for the treatment of such water are carbonate of soda and caustic soda. These are often fed into the boiler and will precipitate the carbonate of lime and sulphate of lime there, requiring the sediment to be blown out or otherwise removed periodically.

296. Describe the action of caustic soda on carbonate of lime and sulphate of lime in water containing both of these ingredients.

The soda precipitates the carbonate of lime, and in so doing carbonate of soda is formed, which, in turn, combines with the sulphate of lime, precipitating it in the form of insoluble carbonate of lime, and forming sulphate of soda, which is very soluble and harmless..

297. How should water containing only sulphate of lime be treated?

Water containing only sulphate of lime may be treated with carbonate of soda. The amount of carbonate of soda in grains, required per gallon to precipitate the sulphate of lime, is found by multiplying the number of grains per gallon of the latter substance by 0.78.

298. Does the use of soda actually remove lime from the inside of a boiler?

No. All that the soda can do is to facilitate the separating of the lime and to cause it to deposit in a soft state. This sediment must be removed periodically.

299. How can acid water be neutralized?

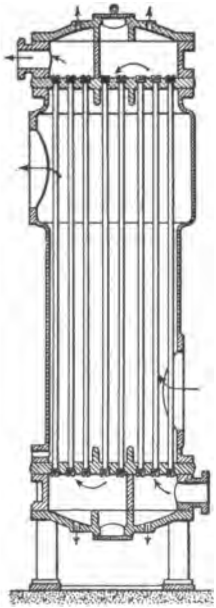
Acid water can be neutralized by means of an alkali, soda probably being the best one. The amount of soda to be used can be found by trial, adding soda until the water will turn red litmus paper blue.

300. What is a skimming apparatus? Describe one.

It is a device placed on the inside of a boiler to collect the scum. A spoon-shaped receptacle or a shallow trough is placed in the boiler, with its top 2 or 3 inches below the normal water level, and the surface blow-off pipe connected to the bottom.

301. What are the advantages of a live-steam feedwater heater?

It purifies the water, since carbonate of lime and sulphate of lime become insoluble if the water is sufficiently heated. It effects a saving in fuel and, by reason of the delivery of very hot water, also tends to reduce repair bills and therefore it increases the life of



Live-steam Feedwater Heater.

a boiler on account of the decrease in expansion and contraction.

302. Explain how a live-steam feedwater heater purifies the feedwater.

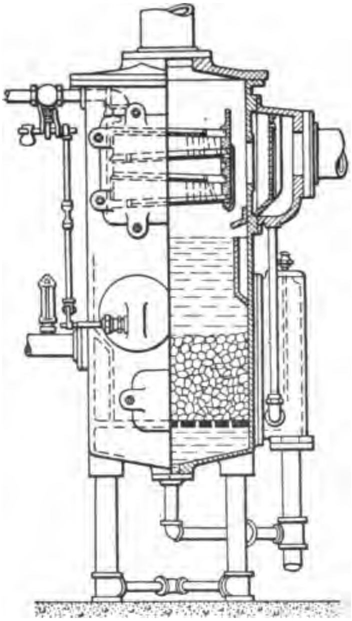
Live-steam water heaters are made in a variety of ways; some are constructed with removable pans; others, with settling chambers, depending on the use of a blow-off and occasional opening up of the heater for the removal of the sediment. Live steam from the boiler enters through a pipe and heats the water in the heater to a temperature nearly equal to its own, and in so doing precipitates those impurities that become insoluble by heat. Mud and earthy matter deposit on the inside of the pans, while scale-forming substances coat the outside of the pans. The sediment must be removed periodically, the pans being easily removable for the purpose. In other heaters, the scale-forming substances and nearly all other foreign matter in mechanical suspension precipitate and collect in the bottom of the settling chamber, whence they can be removed by opening a blow-off valve and occasionally opening up the heater.

303. Into what classes are exhaust-steam feedwater heaters divided?

Exhaust-steam feedwater heaters are divided into two general classes, known as open heaters and closed heaters.

304. Describe an open exhaust-steam heater.

Open exhaust-steam heaters may be divided into two classes: The "direct-contact open heater" and the "coil open heater." In the open direct-contact heater the exhaust steam and feedwater mix, most of the steam being condensed. Consequently, all the oil or grease carried over from the engine in the exhaust steam will mingle with the heated water. To prevent this oil from entering the boiler, it must be removed either by filtration or by means of some skimming apparatus. In a coil open heater the steam and water do not mingle and no provision for the removal of oil is necessary. Open heaters must always be placed on the suction side of the feed-pump, and since they furnish hot water to the pump, it is necessary to place them several feet above in order that the water may flow into the pump by gravity. Direct-contact open heaters will heat the feedwater to a higher temperature than open heaters of the coil type and will cause less back pressure on the engine. Very often a temperature of 210° is obtained. A coil heater will not heat the water sufficiently hot to make any scale-forming substances insoluble, but will heat the water hot enough to cause a marked economy in the use of fuel.



Open Exhaust-steam Feedwater Heater.

305. Should open feedwater heaters be used with an injector? Why?

No. The injector requires the water flowing to it to be cold in order to work.

306. Describe the closed exhaust-steam heater.

In a closed exhaust-steam heater, the steam does not come into contact with the water, and the heater is placed between the feed-pump, or injector, and the boiler, so that the feed-pump handles cold water. The heating surface is generally made of tubes; sometimes the water is inside the tubes and sometimes it is outside, the former being the more general plan. Closed heaters are made in a great variety of forms, all of which, however, embody the same principles.

307. How would you test the feedwater, or the water in the boiler?

A quantitative analysis cannot be made by any one except an expert chemist having a well-appointed laboratory and the proper apparatus; a qualitative analysis for the most common impurities can be easily made, however, with the aid of chemicals procurable in almost any drug store. Such an analysis will show what kinds of impurities are present, but will not show the amounts.

308. How should feedwater be tested for corrosiveness?

This may be done by placing a small quantity of the water to be tested into a glass tumbler and adding a few drops of **methyl orange.** If the sample of water is acid, and therefore corrosive, it will turn pink. If it is alkaline, and hence harmless, it will be yellow. The acidity may also be tested by dipping a strip of **blue litmus paper** into the water. If it turns red, the water is acid. This method is not as sensitive as the previous one, which should be used in preference.

309. How should litmus paper be kept in stock?

It should be kept in a bottle with a glass stopper, as exposure to the atmosphere will deteriorate the paper.

310. Describe a method for testing water for carbonate of lime.

Pour some of the water to be tested into an ordinary tumbler. Add a little ammonia and ammonium oxalate; then heat to the boiling point. If carbonate of lime is present, a precipitate will be formed.

311. Describe a method for testing water for sulphate of lime.

Pour some of the water to be tested into a tumbler and add a few drops of hydrochloric acid. Add a small quantity of a solution of barium chloride and slowly heat the mixture. If a white precipitate is formed, which will not redissolve when a little nitric acid is added, sulphate of lime is present.

312. Describe a method for testing water for organic matter.

Pour some of the water to be tested into a tumbler and add a few drops of pure sulphuric acid. To this add enough of a pink-colored solution of potassium permanganate to make the whole mixture a faint rose color. If the solution retains its color after standing a few hours, no organic substances are present.

313. Describe a method for testing water for matter in mechanical suspension.

Keep a tumbler full of the water in a quiet place. If no sediment is formed in the bottom of the tumbler after standing for a day, there is no mechanically suspended matter in the water.

THE STEAM ENGINE

314. How are steam engines usually classified?

According to the kind of **service**, as stationary, locomotive, marine, etc. According to number and arrangement of **cylinders**, as simple, compound, triple expansion, quadruple expansion, duplex, etc. According to the type of **valve** used to control the distribution of steam, as plain slide-valve, automatic cut-off, Corliss, etc. According to the motion of the **piston**, as reciprocating and rotary. Each of these types may be horizontal or vertical, condensing or non-condensing, and, except the rotary engine, single acting or double acting.

315. Name the stationary and movable parts of a plain slide-valve engine.

The stationary parts are: the steam cylinder, the steam ports, the steam chest, the exhaust port, the cylinder heads, the steam supply and exhaust pipes, the guide bars, the shaft bearings, and the bed, or frame of the engine. The movable parts are: the piston, the piston rod, the crosshead, the crosshead pin, or wrist-pin, the connecting-rod, the crank, the crankpin, the crank-shaft, the flywheel, the eccentric, the eccentric strap, the eccentric rod, the rocker, the valve rod or stem, and the slide valve.

316. Define the terms, head end and crank end of a cylinder.

The end of the cylinder that is the farthest away from the crank is called the **head end**; the end that is nearest the crank is called the **crank end.**

317. Define the term, the stroke of an engine.

The distance passed over by the piston during half a revolution of the crank is called **the stroke** of an engine, and is equal to the diameter of the circle described by the end of the crank, or it is equal to twice the length of the crank, this length being measured from the center of the crankpin to the center of the crankshaft. The stroke is also equal to the travel of the crosshead, since the piston and crosshead are rigidly fastened to the same piston rod.

318. Define the terms, the forward stroke; the return stroke.

The stroke from the head end to the crank end of the cylinder is called the **forward stroke**; the one from the crank end to the head end, the **return stroke.**

319. Define the term the reciprocating parts of an engine.

Those parts of the engine that have a to-and-fro, or **reciprocating** motion, are called the **reciprocating parts.**

320. Define the term, the valve gear of an engine.

The **valve gear** of an engine may be defined as that part of the mechanism which acts to control the distribution of steam to the cylinder. In the plain slide-valve engine, the valve gear consists of the eccentric, eccentric rod, rocker-arm or valve-stem guide, valve stem, and the valve. In the different types of reversible engines, or variable and automatic cut-off engines, the valve-gear includes the mechanism by means of which the motion of the valves is governed so as to change the direction of motion of the engine or vary the amount of work done in the cylinder.

321. Define the term, the bore of the cylinder.

The **bore** of the cylinder is its diameter.

322. How is the size of an engine expressed?

The **size** of an engine is generally expressed by giving the diameter, or bore of the cylinder and the stroke in inches.

323. What is the object of having the cylinder counterbored at the ends?

Were it not for the **counterbore,** into which the piston partly projects at the end of each stroke, the piston would not wear the cylinder walls their entire length, and shoulders would be formed at each end of the cylinder. When the wear of the joints in the connecting-rod is taken up, the length of the connecting-rod is slightly decreased, and the piston is moved slightly towards the crank end of the cylinder. In this case the shoulder would cause an undesirable pounding of the piston.

324. What is the object of the piston rings?

The piston fits loosely in the cylinder and **split rings** are inserted, which spring out so as to press against the walls of the cylinder and prevent leakage of steam between the wall of the cylinder and the piston. Usually, a **follower plate** is supplied, which is bolted to the head end of the piston in order to hold these split rings in place.

325. How can a leaky piston be detected?

To detect a leaky piston, turn the engine until the piston is at a short distance beyond the beginning of the stroke, block the flywheel, open the relief cocks, or the indicator taps, and admit steam to the piston. A steady escape of steam through the relief cocks, or indicator taps, will indicate a leaky piston. The slide valve should be tested first to make sure it is not leaking.

326. What is the object of the guide bars on an engine?

The **guide bars** constrain the crosshead to move exactly in line with the axis of the cylinder, thus relieving the piston rod of all bending stresses.

327. Describe (a) the object of the connecting-rod; (b) how it is joined to crosshead and crank; (c) how it compares with the crank in length.

(a) The **connecting-rod** forms the connecting link between the crosshead and crank. (b) The joint between the crosshead and connecting-rod is made by the **crosshead pin**, and that between the connecting-rod and crank by the **crank pin.** (c) Connecting-rods are usually made from 4 to 6 times the length of the crank.

328. What is a piston rod?

A **piston rod** is a round bar rigidly connected to both piston and crosshead.

329. What is the object of the eccentric?

To impart motion to the slide valve.

330. Describe the eccentric and its action.

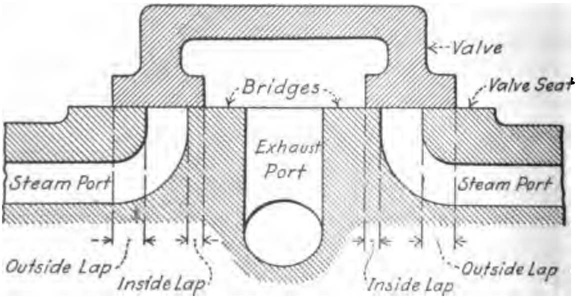
The **eccentric** consists of a circular disk of iron, having a circular hole **not** in the center of the disk. It is keyed or fastened by setscrews to the shaft and revolves with it. The center of this disk is called the **eccentric sheave.** As the shaft revolves, the center of the sheave will describe a circle, whose center is the center of the shaft. Consequently, the eccentric strap and the eccentric rod, to which the strap is fastened, will be moved horizontally, during a half revolution, a distance equal to the diameter of the circle described by the center of the sheave. This distance is commonly called the **throw** of the eccentric. The distance between the center of the eccentric and the center of the hole or shaft is called the **radius** of the eccentric, or the **eccentricity.** The throw is twice the radius.

331. Define lap.

Lap is that projecting part of a slide valve which is more than is necessary to cover the steam ports when the valve is in mid-position.

332. Explain the difference between outside lap and inside lap of a D slide valve.

Outside lap is given a slide valve to cause it to cut the steam off at a given point of the stroke of the piston, and thus to make the steam work by its expansion. **Inside lap, or exhaust lap,** is given a slide valve to cause it to close the exhaust port before the piston reaches the end of its stroke, and thus to compress the steam in front of the piston so as to form a cushion.



D Slide Valve.

333. **Describe the D slide valve.**

The D slide valve is the most common of the different kinds of valves used to distribute the steam in the engine cylinder. It consists of steam ports, bridges, exhaust passage, valve seat and valve flanges, or face. The flanges of the valve are made wider than the ports which they cover. This extra width is called "cover." That part of the extra length which is more than is necessary to cover the system of steam ports when the valve is in mid-position, is called the outside lap. The inside part that projects over beyond the exhaust edge of the port when the valve is in mid-position, is called the inside or exhaust lap.

334. **Define angle of advance.**

On account of the lap, the slide valve and the eccentric center have to be moved ahead of their central positions in order to bring the edge of the valve to the edge of the port. The angle that the eccentric radius then makes with the position it would be in at this time if there were no lap or lead is called **the angle of advance.**

335. **What is back pressure?**

The pressure on the exhaust side of the piston is termed **back pressure.**

336. **What causes back pressure on the exhaust side of a piston?**

The size of the exhaust port is limited by practical considerations and the exhaust is not perfectly free. This, in addition to the atmospheric pressure, causes back pressure.

337. **Define the point of cut-off.**

At a certain point of the stroke of the piston the valve closes the steam port, and from there to the end of the stroke the steam in the cylinder expands. This point in the stroke is called the **point of cut-off.**

338. **Define the point of compression.**

At a certain point of the stroke of the piston the inside edge of the valve closes the exhaust port, and from there to the end of the stroke, the steam in front of the piston is compressed. This point in the stroke is called the **point of compression.**

339. Define point of release.

After steam is cut-off and the work is done by expansion, the movement of the valve will finally permit the steam in the cylinder to pass into the exhaust port. This point of the stroke is called **the point of release.**

340. Does the work done by expansion end as soon as the point of release takes place?

Theoretically it ends, but on account of the limitation in the size of the ports, there will still be a slight amount of work done by the expansion, owing to the inability of the steam to escape instantly.

341. What are the effects of increasing and decreasing the outside lap of a D slide-valve?

Increasing the outside lap leads to earlier cut-off and more expansion, while decreasing the outside lap leads to later cut-off and less expansion.

342. What are the effects of increasing and decreasing the inside lap of a D slide-valve?

Increasing the inside lap causes the compression to begin earlier in the stroke and causes the release to take place later. Decreasing the inside lap causes the compression to begin later and the release to take place earlier in the stroke.

343. Define lead.

Lead is the amount of opening of the steam port when the piston is at the end of its stroke.

344. How would you give a valve its lead?

By increasing the angle of advance. That is, the eccentric sheave must be moved ahead instead of being placed so that edges of valve and port are in line when the piston is at the end of its stroke.

345. With an ordinary direct slide valve, what is the position of the eccentric: (a) when the valve has neither "lap" nor "lead"; (b) when the valve has lap and lead, and the valve rod and eccentric rod move in the same direction; (c) when the valve has lap and lead, and the valve rod and eccentric rod move in opposite directions?

With an ordinary direct slide valve (a) when the valve has neither lap nor lead the eccentric must make an angle of 90° with the crank; (b) when the valve has lap and lead, and the valve rod and eccentric rod are moving in the same direction, the eccentric is set **ahead** of the crank, and the angle between the crank and the eccentric is 90° + the angle of advance; (c) when the valve has lap and lead, and valve rod and eccentric rod are moving in opposite directions, the eccentric must be placed **behind** the crank, and the angle between the crank and eccentric is 90° — angle of advance. This rule applies whether the engine runs **over** or **under.**

346. In what cases is a lever or rocker-arm used?

The **lever** or **rocker-arm** is used in the following cases: where the eccentric cannot be located on the shaft so that the eccentric rod and valve stem will be in the same straight line; where it is desirable to make the throw of the eccentric less or greater than the valve travel; where it is desirable to make the valve rod and eccentric rod move in opposite directions..

347. What is the difference between a direct and an indirect slide-valve?

A slide-valve is said to be **direct** when it opens the left port upon moving to the right and closes it by moving to the left. A valve is said to be **indirect** when it opens the left steam port by moving to the left and closes it by moving to the right.

348. Describe the piston slide valve.

Piston valves are made both as direct and as indirect valves. In the case of the direct piston valve, its action is exactly the same as that of the ordinary plain slide-valve. The indirect piston slide-valve consists of a hollow cylinder sliding in a cylindrical valve seat. The ports extend clear around the valve, except for stiffening bars. The steam is admitted into a central chamber and the exhaust steam escapes out of the two ends. To give a larger admission passage, steam also passes into the center of the valve through channels and thence into the port.

349. With an ordinary indirect slide-valve, what is the position of the eccentric: (a) when the valve rod and eccentric rod move in the same direc-

tion; (b) when the valve rod and eccentric rod move in opposite directions?

With an ordinary indirect slide-valve (a) when the valve rod and eccentric rod are moving in the same direction the eccentric is set **behind** the crank and the angle between them should be made to equal 90° — the angle of advance; (b) when the valve rod and the eccentric rod move in opposite directions, the eccentric is set **ahead** of the crank and the angle between them should be made to equal 90° + the angle of advance.

350. **What effect has the connecting-rod on the steam distribution of a simple slide-valve?**

The connecting-rod will tend to cause the valve to cut-off and release steam, as well as to close the exhaust port, later on the forward stroke of the piston than on the return stroke. The longer the connecting-rod, the less will be this disturbance; and the shorter the connecting-rod, the greater the disturbance.

351. **What is the difference between the plain D slide-valve and the double-ported valve?**

With the same travel, the double-ported valve gives double the opening to steam that the plain valve does. Otherwise, the two valves are alike in all respects.

352. **What is the advantage of a double-ported valve?**

When an engine has a high piston speed, the plain D valve does not open the port fast enough to allow the steam to follow up the moving piston and keep up full pressure in the cylinder. The double-ported valve is used, giving double the opening for steam with the same travel.

353. **When is an engine said to be on its dead center?**

An engine is said to be on its dead center when the crank and connecting-rod lie in the same straight line.

354. **What is meant by inner or head-end dead center and outer or crank-end dead center?**

When the crank and connecting-rod lie in the same straight line and the piston is at the head-end of the cylinder, the engine is said to be on its **inner, or head-end dead center.** If the piston is at the crank-end of the cylinder, with the crank and connecting-rod in the same straight line, the engine is said to be on its **outer, or crank-end dead center.**

355. Describe a common method of placing the engine on its dead center.

Turn the engine ahead until the crosshead is very near the inner end of its travel, and make a mark on one of the guides opposite the outer edge of the crosshead. While the engine is in this position, take a tram, the length of which is about equal to the distance from the floor to the center of the crank-shaft, place one end upon the floor, or on the engine bed if possible, and with the other end make a mark on the edge of the flywheel. Now turn the engine ahead past the dead center and beyond, until the outer edge of the crosshead again comes even with the mark on the guide, and again mark the edge of the flywheel with the tram. Now make a third mark on the edge of the flywheel half way between the two marks already made and turn the wheel until this third mark comes opposite the upper end of the tram. By making other marks for the other end of the guide, the flywheel may be marked for the outer dead center.

356. Describe a method for setting a slide-valve.

To set a slide-valve, put the engine on its dead center. Place the valve on the seat and connect it with the eccentric-rod. Shift the eccentric on the shaft in the direction the engine is to run, until the valve has the desired lead. Tighten up the set screw. Turn the engine in the direction it is to run until it is on the other dead center. If the lead is the same as at the other end, the valve is correctly set. If it is not the same, the valve rod must be lengthened or shortened until the lead is the same at both centers. If, now, the lead is less than desired, shift the eccentric forward a little on the shaft; if the lead is a little too great, shift the eccentric backward.

357. What is meant by piston clearance?

The short distance between the piston and the head, when the piston is at the end of its stroke, is called **piston clearance.**

358. What is the object of piston clearance?

Piston clearance is allowed so that a slight change in the length of the connecting-rod or piston rod will not cause the piston to strike the head at the end of its stroke. The object is also to provide a small space between the piston and head in which any small quantity of water in the cylinder may collect when the piston is at the end of its stroke, and thus prevent the breaking of some part of the engine.

359. Describe how to measure the piston clearance.

To measure the piston clearance at either end of the cylinder, first put the engine on its dead center for that end and make a mark on the guides corresponding to some convenient point of the crosshead. Next, disconnect the connecting-rod and push or pull the piston until it strikes the head. The distance of the chosen point on the crosshead (in its new position) from the mark made on the guides is the piston clearance for that end of the stroke.

360. Define the clearance volume.

The clearance volume may be defined as the volume of steam between the valve and the piston when the latter is at the end of its stroke.

361. How may the clearance volume be measured?

The clearance volume may be measured by putting the engine on a dead center and pouring in water until the space between the piston and the cylinder head and the volume of the steam port leading into it are filled. The volume of the water poured in is the clearance. Since water is likely to leak past the piston, it is best to use a heavy oil for measuring the clearance volume.

362. How is the clearance volume expressed?

The clearance volume may be expressed in cubic feet or cubic inches, but it is more convenient to express it as a percentage of the volume swept through by the piston.

363. What is meant by apparent cut-off?

The point of the stroke of the piston at which the steam is cut-off.

364. What is the real cut-off?

It is the ratio between the volume of steam in the cylinder and clearance space when the piston is at the cut-off point and the volume of steam in cylinder and clearance space when the piston is at the farther end of the stroke.

365. How would you find the real cut-off?

To find the real cut-off, add the clearance, expressed as a per cent. of the stroke, to the apparent cut-off, expressed in per cent., and multiply the sum by 100; divide the product by 100 plus the clearance, in per cent.

366. What is the ratio of expansion?

The ratio of expansion, also called **the number of expansions,** is the ratio between the volume of steam in the cylinder and clearance space when the piston is at the far end of its stroke and the volume in the cylinder and clearance when the piston is at the cut-off point.

367. How would you find the ratio of expansion?

The ratio of expansion is found by dividing 100 by the real cut-off in per cent.

368. How would you find the area of the steam pipe needed for an engine or pump?

To find the area in sq. ft. of the steam pipe needed, multiply the area of the piston in sq. ft. by the piston speed in feet per minute and divide the product by 6,000.

369. How would you find the area of the exhaust pipe or exhaust port needed for an engine or pump?

To find the area of the exhaust pipe or exhaust port, multiply the area of the piston by the piston speed and divide the product by 4,000.

370. How would you find the area of the steam ports needed for an engine or pump?

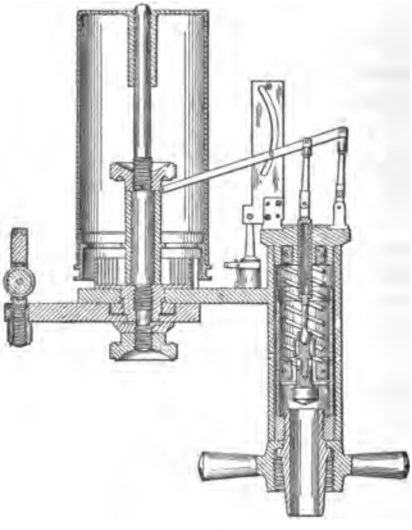
To find the area of the steam ports needed, multiply the area of the piston by the piston speed; divide the product by 7,500 if the port is short and direct, and by 6,000 if the port is long and tortuous.

371. Describe a rotary engine and its construction.

Rotary engines have been constructed in a great variety of forms. They usually consist either of a rotary piston of some suitable form, bearing against a rolling, sliding, or swinging abutment, or of interlocking pistons similar to those found in the Root blower. Abutments cannot be kept steam-tight for any length of time, and generally will cause bad steam leakage into the exhaust in a short time. Rotary engines of the interlocking piston pattern either commence to leak badly after short service or are very noisy. Some rotary engines are valveless and very simple, but extremely costly to operate. Some have eccentric pistons; these rapidly wear the cylinder walls and bearings owing to the difficulty of counterbalancing them properly for high speeds. On the whole the rotary engine, owing to inherent irremovable constructive difficulties, will never be of great commercial value.

372. What is an indicator?

An indicator is an instrument that can be readily applied to a steam engine for the purpose of obtaining a diagram of the pressures in the cylinder.



The Indicator.

373. Describe briefly the construction of an indicator.

The indicator is made in a variety of forms that differ only in minor details, the general principles involved in all being the same. The instrument consists essentially of a cylinder containing a piston and a spring. By turning a cock connected to the small pipe to which the indicator is attached, steam may be admitted to, or shut off from, the cylinder of the indicator at pleasure. When steam is admitted, its pressure causes the piston to rise. The spring is compressed and resists the upward movement of the piston. The height to which the piston rises is in exact proportion to the pressure of steam, and as the steam pressure rises and falls, the piston must rise and fall accordingly. To register this pressure a pencil and paper are attached in such a manner that the pencil is made to press against the paper. To obtain a long pencil movement combined with a short travel of the piston, the pencil is attached to the long end of a lever the short end of which is connected to the piston. The pencil motion, for most indicators, is 4, 5 or 6 times that of the piston. The pencil point is forced to move in a vertical straight line by an arrangement of links and joints, forming what is called a **parallel motion.**

374. **Explain what is meant by the scale of the indicator spring.**

The height to which the piston will rise under a given steam pressure depends upon the stiffness of the spring. Therefore, indicators are usually furnished with a number of springs of varying degrees of stiffness, which are distinguished by the numbers 10, 20, 30, 40, etc. These numbers indicate the pressure per square inch required to raise the pencil 1 inch and are called **the scale of the spring.**

375. **About what scale of spring is usually selected for a given boiler pressure?**

The scale of the spring selected should be about one-half the boiler pressure. For example, for a steam pressure of 75 pounds per square inch a 40 spring should be used.

376. **Describe how the indicator registers the steam pressures in the engine cylinder in relation to the position of the piston.**

To register the steam pressures in relation to the position of the piston, a cylindrical drum, on which the paper can be placed, is provided. This drum can be revolved on its axis by pulling a cord which is coiled around it. When the pull is released, a spring rotates the drum back to its original position. The cord is attached to some part of the engine that has a motion proportional to the motion of the piston. The motion of the drum, therefore, is also proportional to the motion of the piston.

377. **How would you connect the indicator to the engine?**

To connect the indicator to the engine a hole is drilled in the clearance space of the cylinder and tapped for a ½ inch nipple. If this hole is in the top of the cylinder, the indicator cock may be screwed directly into it, or, if more convenient, a nipple and coupling may be used. If the cylinder is tapped at the side, a nipple and elbow may be used so as to bring the indicator into a vertical position. Some engineers, however, prefer to omit the elbow and attach the indicator in a horizontal position. With many engines that have not been provided with special indicator attachments, it will be found that holes for this purpose may be conveniently drilled and tapped in the cylinder heads. On account of the resistance offered by the pipe and elbows to the flow of steam to the indicator, it is preferable to have an indicator at each end of the cylinder, but if that is not convenient, one indicator may be connected with both ends of the cylinder by means of a three-way cock.

378. **Should the indicator connection be made on the side of the cylinder directly opposite to the steam ports? Why?**

No. The current of entering steam would strike against the opening leading to the indicator, and the pressure shown by the diagram would thereby be considerably increased.

379. **Describe the gas-engine indicator.**

The indicator specially adapted to gas engines is sometimes applied to steam engines, pumps, and hydraulic machinery when high pressures are used. The indicator cylinder has two bores, a larger and a smaller bore. The larger bore is ½ square inch area, the size usually employed when testing a steam engine, and the area of the smaller bore is ¼ square inch. The piston fitted to the smaller bore is used when indicating a gas engine or a very high pressure steam engine. It gives but half the movement of the pencil given by the larger piston; so, if the spring used is stamped 40, the calculations, when using the smaller piston, must be made as if an 80-pound spring had been used. The pencil movement is also of special design, the moving parts being stronger and more rigid than those used on regular steam-engine patterns. With the regulation piston of ½ square inch area in the larger bore, the indicator may be used for steam engines with ordinary pressures.

380. Describe the indicator used on ammonia cylinders of refrigerating machines.

Indicators used on ammonia cylinders have working parts made of steel instead of brass, because ammonia has no effect on steel, but rapidly corrodes brass. In case it is not possible to procure an ammonia indicator, an ordinary steam-engine indicator will answer the purpose, provided the piston is removed after every set of cards is taken and both cylinder and piston are wiped dry and well covered with oil. This will prevent the ammonia gas from attacking the portions of the indicator made of brass.

381. What is a reducing motion on an indicator and what is its purpose?

The motion of the indicator paper drum is nearly always taken from the crosshead. Since the stroke of the crosshead is longer than the circumference of the drum, it is necessary to arrange a form of mechanism, some point of which will copy to a reduced scale the stroke of the piston. Such a mechanism is called a **reducing motion.**

382. Describe some of the reducing motions used.

While the **pantograph** and **lazy tongs** are excellent forms of reducing motion, the **swinging-lever** forms one of the simplest reducing motions in use. It is a lever with one end pivoted at some convenient fixed point above the guides. The other end is slotted and fits over a pin in the crosshead. The cord is attached to the lever at some point below the pivoted end, and is guided by a pulley so that it leaves the point of attachment in a direction parallel to the line of the motion of the crosshead.

383. Is the swinging-lever a perfect reducing motion? Why?

No. The length of the long arm of the lever varies, while the length of the short arm remains constant. This results in a variation in the relative motions of crosshead and cord for different parts of the stroke, and the diagram obtained is, in consequence, distorted.

384. To secure good results from the swinging-lever reducing motion what should be particularly observed?

To secure good results the lever should always be suspended from such a point that when the crosshead is at the middle of its stroke, it will be perpendicular to its line of motion. The accuracy of the motion will, in general, be increased by increasing the length of the lever. For most purposes, a lever, whose length is twice that of the stroke, will be sufficient, but in some cases a lever shorter than this is used.

385. How would you find the distance from the pivot at which to connect the cord; the length of the diagram, and the distance from the pivot of the lever to the point where it is connected with the crosshead being known?

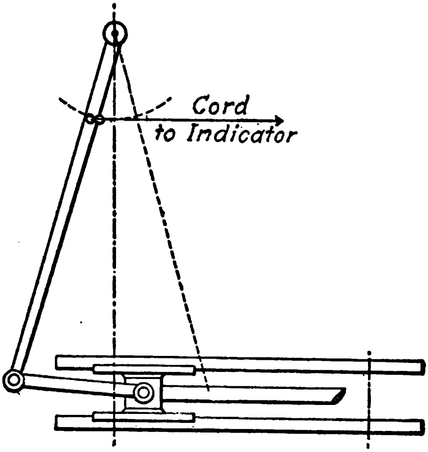
Multiply the length of the diagram by the distance from the pivot to the point of the lever at which it is connected with the crosshead, and divide the product by the length of the stroke.

386. Describe the method of reducing the motion of the crosshead by means of reducing wheels.

Reducing wheels form a more accurate method of reducing the motion of the crosshead to the required value for the paper drum. Some of these wheels are designed to be attached directly to the indicator, while others are provided with means for clamping to some point on the engine bed. A cord is attached to a bar or rod fastened to the crosshead in such a manner that the cord will lead from it to a wheel in a line parallel with the line of motion of the crosshead, while another cord leads from a smaller pulley to the indicator drum. The smaller pulley can be removed and replaced by one of several others of different sizes. The proportions of the two pulleys can thus be varied so as to secure the desired length of diagram. The hub of the larger wheel contains a spring that is wound up when the cord is unwound from the wheel by outward motion of the crosshead. When the crosshead makes its return stroke, the spring turns the wheel and winds the cord on again.

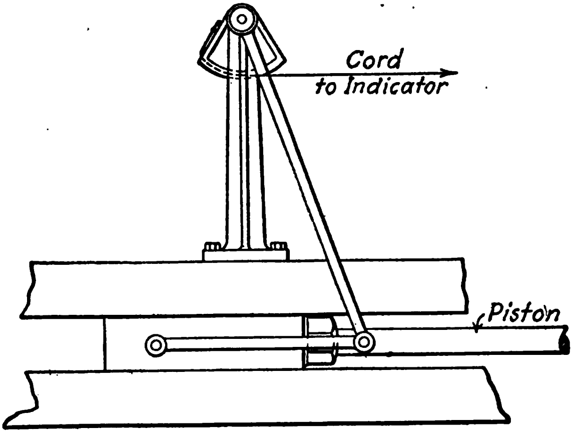
387. **What form of reducing motion may be recommended for engines having a high rotative speed? Why?**

A swinging lever, if made of stiff and light wood with joints bushed and neatly fitted, will give good results. The shocks and stresses in a reducing gear, set up by the quick changes in direction of motion when an engine has a high rotative speed, cause a springing of the parts that will distort the diagram and wear the joints very rapidly. With reducing wheels, the quick reversals of the direction of rotation that take place at high speeds make it necessary



Reducing Motion.

to use a stiff spring to overcome the inertia of the wheel.



Reducing Motion.

388. State what details should be observed regarding the indicator cord. Why?

The reducing motion and indicator should always be so arranged that the cord may be led to the paper drum in the shortest and most direct practicable line. When the cord is attached to a pin on the reducing motion, it must be guided so as to leave the pin in the line of its motion; the use of guide pulleys should, however, be avoided as much as is practicable. Since the stretching of the cord results in a distortion of the diagram, a special braided cord, of the type generally supplied with indicators, should be used. In the case of large engines, where long cords are required, a fine copper or steel wire may be used to advantage.

389. What methods are used to stop the motion of the paper drum when it is required to change the paper or when the indicator is not in use?

A common method is to have a book at the end of the cord attached to the paper drum; the cord from the reducing motion has a loop into which the hook may be fastened when it is desired to operate the paper drum. The loop is to be made so that the length of the cord may be readily adjusted. To prevent the cord leading from the reducing motion from being thrown about and getting tangled when it is unhooked from the cord leading to the paper drum, it is well to have a rubber band fastened in a convenient position and provided with a hook into which the loop may be secured. A number of other useful devices are in use. Some paper drums are provided with a stop motion that will hold them in place and prevent the cord from being wound on. This has the same effect as lengthening the cord. When speeds are high, it is sometimes quite troublesome to connect the cord without a stop motion, unless after considerable practice.

390. **With an engine having two or more cylinders, describe the method used for taking diagrams simultaneously from each end of all the cylinders.**

The simplest and most successful device used for taking simultaneous diagrams is an electromagnet that is attached to the indicator. When a number of indicators are to be operated simultaneously, the electromagnets of all are connected by a wire; when a current is sent through the wire by pressing a button or key, each electromagnet pulls its pencil against the paper and holds it there until the circuit is opened.

391. **What directions for taking indicator diagrams would you observe yourself or issue to your assistant?**

The makers of indicators furnish very complete instructions for the care and use of their instruments; these instructions should be carefully studied before attempting to use a new indicator, or one with which the user is not thoroughly familiar. The following directions for taking diagrams apply to all makes of indicators: Before attaching the indicator to the engine, see that it is clean and in good working order. The piston should move freely. See that the joints of the various levers and links are oiled with fine oil and that they are slack enough to avoid friction, yet not so slack as to allow the pencil to shake. Adjust the pencil so that it just touches the paper and sharpen the point so that it makes a very fine light line. Select a spring that will give a diagram about 1½ or

1¾ inches in height. If, upon trial, the spring chosen makes a wavy line, choose a stiffer spring. See that there is no backlash between the piston and spring. Adjust the length of the cord so that the drum turns backward and forward without striking either of the stops at the end of the travel. Keep the drum moving only when taking diagrams. Unhook the cord before putting a paper on the drum. In putting the paper on the drum, see that it fits the drum without wrinkles, and fold back the projecting edges over the clips, so that they will not touch the pencil lever. Before taking the diagram, turn on the steam for a minute or so, to warm the indicator; then press the pencil lightly on the paper long enough to take a single diagram. Shut the cock and again press the pencil to the paper. Since the indicator piston is then only subjected to atmospheric pressure, the pencil will make a straight line called the **atmospheric line.** Disconnect the cord and remove the paper. Write on the paper the scale of the spring used, the speed of the engine, and any other desired particulars. If one indicator is used for both ends, first open the three-way cock to admit steam from one end. Take the diagram and open the cock to the other end, and take the diagram from that end. Then shut off the steam entirely and take the atmospheric line.

392. If the indicator drum touches either or both of the stops at the end of the travel, state the trouble and the remedy.

When the drum touches one or the other of the stops, the cord is either too short or too long and must be either lengthened or shortened. If it touches both, the travel of the drum is too great, and the cord must be fastened to a point on the reducing motion having less travel.

393. What is the purpose of an indicator diagram?

To enable the engineer to determine with a considerable degree of certainty the general condition of the engine, and the various pressures in the cylinder. The diagrams also disclose the faults in valve setting and steam distribution, and sometimes imperfections in the construction of the engine.

394. Name the different points and lines of an indicator diagram.

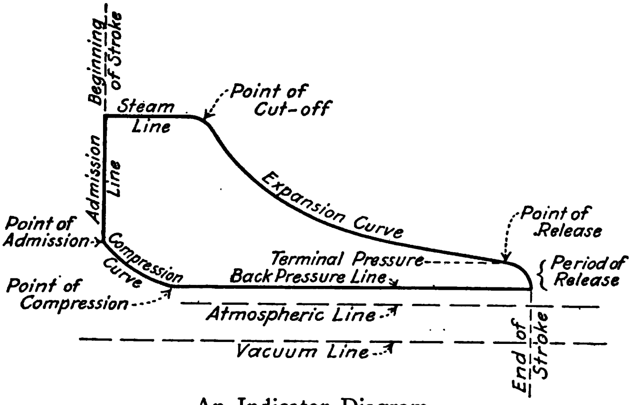
The points of the diagram are: the beginning of the stroke; the point of cut-off; the point of release; the end of the stroke; the point of compression; and the point of admission. The lines between these points are named as follows: the steam line; the expansion curve; the period of release; the back pressure line; the compression curve; and the admission line.

395. What is the vacuum line and how is its position located?

The **vacuum line** is a line of no pressure. When it is desirable to show it on the indicator diagram, it is drawn below and parallel with the atmospheric line.

396. What is the distance between the vacuum and atmospheric lines on an indicator diagram?

The distance between them is equal to the atmospheric pressure divided by the scale of the spring. Thus, if the scale of the indicator spring is 30, the vacuum line lies $\frac{14.7}{30} = .49$ inch below the atmospheric line. When the engine is located at a great altitude above the sea level, and great accuracy is desired, the vacuum line should be located in accordance



An Indicator Diagram.

with the indication of the barometer. Then the distance between the two lines may be found by multiplying the reading of the barometer (in inches) by .49 and dividing by the scale of the spring. Thus, if the barometer stands at 25 inches and the scale of the indicator spring is 30, the vacuum line should be drawn at a distance $\frac{25 \times .49}{30} = .41$ inch below the atmospheric line.

397. **What is the advantage in taking two diagrams on one card?**

When taking the two diagrams on one piece of paper only one indicator is used. The diagrams are placed one over the other and it is very easy to tell what is taking place in the cylinder at any point of the forward or return stroke.

398. **What are the distinguishing differences between diagrams taken from an engine with releasing gear, of the Corliss type, and diagrams taken from a locomotive or from a high-speed automatic engine?**

When the valves are correctly set and in good woring order, a diagram taken from an engine with releasing gear of the Corliss type will be regular and will show but little compression. The points of cut-off, release, and compression will be sharply marked. A diagram taken from an engine running at high speed will show irregular lines due to the inertia of the moving parts of the indicator. The compression is large, as it should be for engines running at a high speed. The point of cut-off will not be very sharply marked.

399. **State some of the most common faults in valve setting revealed by the indicator diagram.**

Admission may be too early or too late; cut-off may be too early or too late; release may be too early or too late; compression may be too early or too late.

400. **What is the effect of too early admission on the indicator diagram?**

The admission line, instead of being straight, and perpendicular to the atmospheric line, slants backward.

401. When admission is too early, are all other events of the stroke too early?

With a single slide-valve or piston valve, all the other events, cut-off, release, and compression, are also too early. In the case of the Corliss engine, the admission may be too early, while the other points are not affected.

402. How may too early admission be remedied?

With a single slide-valve or piston valve, the remedy is to shift the eccentric on the shaft so as to decrease its angular advance. In the case of the Corliss engine, the fault may be remedied by 'adjusting the link rods so as to give the steam valves more lap, and it may not be necessary to shift the eccentric.

403. What is the effect of too late admission on the indicator diagram?

The admission line, instead of being straight and perpendicular to the atmospheric line, slants forward.

404. When admission is too late, are all other events of the stroke also too late?

With a single slide-valve or piston valve, cut-off, release and compression, are also too late. In case the engine has a Corliss, or other releasing gear, the admission may be too late, while the other points are not affected.

405. How may too late admission be remedied?

In the case of a single slide-valve or piston valve, the remedy is to shift the eccentric on the shaft so as to increase the angular advance. In the case of a Corliss or other releasing gear, the fault may be remedied by adjusting the link rods so as to make the admission earlier by reducing the lap of the admission valves.

406. What is the effect of (a) too early, (b) too late admission on the running of the engine?

(a) The effect of too early admission is to introduce an excessive resistance to the motion of the piston before it reaches the end of the stroke. The result is likely to be pounding at the crosshead, crank, and main bearings. (b) The effect of too late admission is not generally as noticeable or severe as is too early admission, but it causes waste of steam.

407. When the cut-off is too early, what is the effect on the indicator diagram?

When the cut-off is too early, the steam may expand until its pressure is less than the back pressure; in consequence, the expansion line crosses the back-pressure line and forms a loop.

408. When the cut-off is too early, what is the effect on the running of the engine?

It causes a reversal of pressures on the piston, that may result in pounding. The great range in pressure also has a bad effect on the steam consumption. This effect is often observed in automatic cut-off engines working under a light load.

409. When the cut-off is too late, what are the results?

When the cut-off is too late, the terminal pressure is very high. A great deal of the benefit of expansion is lost and there is a consequent waste of steam. With an ordinary plain slide-valve engine, the cut-off is always late. It is not practicable to cut off earlier than ½ stroke without seriously affecting the other events of the stroke.

410. When the compression is too early, what are the results?

When the compression is too early, the steam may be compressed in the clearance space until its pressure rises above that of the steam in the steam chest; when the steam valve opens there is then a flow of steam from the cylinder to the steam chest until the pressures in the cylinder and steam chest are nearly equal.

411. What is the effect of too much compression on the running of an engine?

Too much compression is likely to produce an effect on the running of an engine similar to that produced by too early admission. It offers excessive resistance to the motion of the piston before it reaches the end of its stroke, and causes pounding and heating. It also reduces the effective work of the steam.

412. When compression is too late, how is it shown on the indicator diagram?

This fault is shown on the diagram by a very short compression curve or by the almost complete absence of such a curve.

413. If an indicator diagram shows a material difference in the work done in the two ends of a cylinder, how can this fault be remedied?

With a slide-valve, the fault can be remedied by changing the length of the valve stem so as to make the cut-off take place earlier on the end doing the greater amount of work and later on the other. With an engine having a separate steam valve for each end of the cylinder, either valve may be adjusted so as to make it cut off earlier or later without affecting the other.

414. With an automatic or adjustable cut-off what is the remedy for too early cut-off?

The remedy is either to throttle the steam, to lower the boiler pressure, or to run the engine at a slower speed.

415. With an automatic or adjustable cut-off, what is the remedy for too late cut-off?

This fault may be remedied by raising the boiler pressure so that the same area of diagram will be obtained with an earlier cut-off or by increasing the number of revolutions per minute so as to do the same work with a smaller average pressure. By either method the cut-off will be made to take place earlier in the stroke, and the expansion line will fall nearer to the back-pressure line.

416. If the release takes place too early or too late, what are the effects on the running of the engine?

If the release is too early, there is danger of loss of pressure due to the escape of the steam too early in the stroke; if the release is too late, the escape of the steam will be so much retarded that the back pressure at the beginning of the return stroke will be excessive. Either of these conditions will cause a loss of work.

417. If release takes place too early or too late, how can this be remedied?

The valve should be so designed and set that the drop of pressure from the expansion line to the back-pressure line will occur as nearly as possible at the end of the stroke. If the engine is provided with separate steam and exhaust valves, this condition will best be fulfilled by setting the exhaust valve so that one half of the fall in pressure occurs before the piston begins its return stroke. With a single-valve engine, it is often very difficult to secure a satisfactory release without seriously affecting the other events controlled by the valve.

418. What is the effect of too little compression?

If there is too little compression, the reciprocating parts will not be satisfactorily cushioned. As in the case of "too much compression," the effect will be a sudden reversal in the pressures on the bearings that will produce shocks and heating.

419. How would you determine the exact amount of compression required?

There is no simple rule for determining the exact amount of compression required. The amount of compression required to secure quiet running varies with the speed of the engine, but in no case should the compression line extend above the initial or boiler pressure. It is average practice to compress to about $\frac{9}{10}$ the initial pressure with high-speed engines, $\frac{5}{10}$ with medium-speed engines and from $\frac{2}{10}$ to $\frac{3}{10}$ with slow-speed engines.

420. In addition to faults in valve design and setting, what other faults are revealed by indicator diagrams?

The indicator diagrams reveal the condition of the piston, cylinder, and valves. From the appearance of the diagram it is comparatively easy to locate other faults, such as insufficient port opening, a steam pipe too small for its purpose, a cramped exhaust passage, or an obstructed exhaust pipe.

421. What is meant by the equilateral hyperbola?

In order to locate some of the faults indicated by an indicator diagram, it is convenient to draw in the equilateral hyperbola, which is an average or typical expansion line.

422. If the actual expansion line follows the equilateral hyperbola closely, what does this indicate?

It indicates (if the cut-off occurs at a usual point) that the piston and valves are probably tight, and the amount of cylinder condensation about normal.

423. Why does the actual expansion line generally rise above the equilateral hyperbola near the end of the stroke?

It is thought to be due to reevaporation of steam which was condensed in the cylinder during the early part of the stroke.

424. Explain the processes known as cylinder condensation and reëvaporation.

They may be explained as follows: During the period of exhaust, the cylinder walls are cooled by contact with the relatively cool low-pressure exhaust steam. When the hot steam from the boiler is admitted to the cylinder, a part of it condenses and gives up its latent heat to the cold walls and thus heats them again nearly to the temperature corresponding to the initial pressure; the water formed by this process of condensation is deposited in a thin film on the walls of the cylinder. After cut-off takes place and expansion begins, the pressure of the steam in the cylinder falls until its corresponding temperature is lower than the temperature of the cylinder walls; the walls then give up some of their heat and reëvaporate some of the water. The steam thus formed toward the end of the stroke prevents the pressure from falling as fast as it otherwise would and has the effect of raising the expansion line somewhat above the hyperbolic.

425. If the actual expansion line departs considerably from the hyperbolic, what does it indicate?

This may indicate that steam either enters or leaves the cylinder after cut-off takes place and before release occurs.

426. If the actual expansion line (a) rises markedly above the hyperbolic, (b) falls below the hyper-

bolic, what is the fault?

(a) It is probable that the steam valve leaks and allows steam to enter after cut-off. (b) It is probable that steam was escaping from the cylinder through a leaky exhaust valve or past an imperfectly fitted piston.

427. **If the actual expansion line follows the hyperbolic line closely, is that a positive indication that the valves and piston do not leak?**

No. Steam may leak into and out of the cylinder at the same time and at such rates that the expansion line will appear to be quite satisfactory.

428. **What is the most general method of determining the point of cut-off on an indicator diagram?**

On the Corliss and other releasing-gear engines the valve cuts off very suddenly, the rounding of the diagram near the point of cut-off is very slight, and the point of cut-off is very easily located. In the case of a high speed engine it is sometimes very difficult to determine exactly the point of cut-off from the indicator diagrams. A method for determining the point of cut-off is to prolong the expansion line by means of a smooth curve until it intersects the horizontal through the point representing the initial pressure. The point of intersection is then taken as the point of cut-off.

429. **How is leakage of steam through the exhaust valve or around the piston indicated on the indicator diagram?**

The curvature of the compression line changes as the piston nears the end of the stroke, sometimes forming a hook. If the piston and valves are tight, the compression line will generally curve quite regularly in one direction until it meets the admission line.

430. **What effect has the throttling of steam on the indicator diagram?**

Throttling or any restriction in the passage leading from the boiler to the cylinder has the effect of preventing the flow of steam fast enough to keep the cylinder filled at boiler pressure up to the point of cut-off. This effect is shown on the diagram by a steam line that gradually falls as the piston advances.

431. What effect has a high rotative speed on the indicator diagram?

A high rotative speed generally results in a drop in the steam line, since the valve opening is relatively restricted and steam cannot follow the piston fast enough to keep the pressure up to that at the beginning of the stroke.

432. What causes a high back pressure?

A high back pressure is caused by some obstruction that prevents the free escape of the exhaust. Such a result will be produced by a choked exhaust port, an exhaust pipe that is very long or too small or by discharging the exhaust into a system of pipes for heating a building.

433. To what are wavy lines on a diagram usually due?

Wavy lines on a diagram are generally due to vibrations of the pencil motion when there is a sudden change in pressure, such as takes place when steam is admitted to the cylinder of a high-speed engine, or during the early part of expansion. These effects are common with diagrams from quick rotative speed engines. They are an indication that the indicator piston is in good condition and working freely.

434. What is the reason when an expansion line drops by a series of steps or notches?

The sticking of the indicator piston is generally the cause of such an expansion line. Such line can generally be distinguished from a **wavy line** by the angular appearance of the steps or notches.

435. How may the striking of the paper drum against the stops be detected?

This is rapidly detected by the appearance of the release end of the diagram, which, instead of being rounded, will have angular corners with a nearly vertical line connecting them.

436. What is thermodynamics?

Thermodynamics is that branch of physical science that treats of the relation between heat and mechanical work.

437. What is meant by the term a heat engine?

A device by means of which energy, in the form of heat, developed by the combustion of fuel or derived from any other source, is transformed into mechanical motion in such a manner that it can be made to do useful work.

438. Is the steam engine a heat engine? Why?

Yes. The steam is merely a vehicle by means of which the heat energy developed by the combustion of the fuel in the furnace is transferred to the moving parts of the engine.

439. On what general principle is the action of nearly all heat engines based?

The production of an expansive gas or vapor in a confined space.

440. What is meant by the tension of a gas?

All gases possess the property of expansibility, by virtue of which they expand and fill the space in which they are confined, no matter how great that space may be. This tendency to expand causes the gas to exert a pressure on the walls of the confining vessel. This pressure is called **the pressure or tension of the gas.**

441. Explain how work is done by the expansive force of a gas.

When a volume of gas is confined in a cylinder fitted with a movable piston, the tendency of the gas to expand will exert a pressure on the piston. If the resistance to the motion of the piston is less than this pressure, the piston will be pushed outward against the opposing force; the expansive force of the gas overcomes a resisting force, and in so doing does work.

442. Define the terms (a) adiabatic expansion; (b) isothermal expansion.

(a) When a gas expands and does work at the expense of its own heat, the expansion is said to be **adiabatic**; and the temperature falls. (b) When heat is added to a gas so as to keep the temperature constant during expansion, the expansion is said to be **isothermal.**

443. Define the terms (a) adiabatic compression; (b) isothermal compression.

(a) If the compression of a gas takes place under such conditions that no heat can leave the gas during the change in its volume, the energy represented by the work done on it will appear as heat and the temperature of the gas will be raised; under these conditions we have **adiabatic compression.** (b) If the compression takes place under such conditions that the heat represented by the work done is removed from the gas so as to keep its temperature constant, the compression is **isothermal.**

444. What is the relation between expansion and compression of a gas?

The quantity of work that must be done in compressing a gas adiabatically or isothermally from a given volume to a smaller one is exactly equal to the work that the gas can do when expanding, in the same way in which it was compressed, from the smaller volume to the original. Also, the rise in temperature during adiabatic compression and the quantity of heat that must be abstracted when the compression is isothermal are, respectively, equal to the corresponding fall of temperature, and the quantity of heat that must be added, during adiabatic and isothermal **expansion.**

445. In practice, is the expansion ever purely adiabatic or isothermal? Why?

It is seldom that the expansion is purely adiabatic or isothermal. No cylinder can be so made as to absolutely prevent the transfer of some heat to or from the gas, and it is difficult to impart or abstract heat so as to keep the temperature absolutely uniform.

446. Is there any relation between heat and work during expansion and compression?

It is always found that there is a definite relation between the work done and the sum of the quantities of heat represented by the change in temperature or condition of the gas and the heat imparted to or abstracted from it. This relation shows conclusively that the work done by an expanding gas is always the result of a change of heat to work.

447. What is the relation between the pressure and the volume of a gas during expansion?

If the temperature of the expanding gas (meaning a true gas, not a vapor, like steam), is kept constant, it is found that when the gas has expanded to twice its original volume, the pressure, in accordance with Mariatte's law, is only one-half the original pressure. When the volume is three times as great as the original volume, the pressure is found to be one-third the original pressure, etc.

448. What is an expansion diagram?

It is a graphical diagram representing the relation between the pressure and the volume of an expanding gas.

449. What is the isothermal expansion line on an expansion diagram?

It is the curve that represents the relation between the pressure and volume when the temperature is constant.

450. What is the adiabatic expansion line on an expansion diagram?

It is the curve that represents the relation between the pressure and volume when no heat is added to the gas as it expands, that is, when the expansion is **adiabatic.**

451. Is the relation of volume and pressure of steam when it expands as simple as in the case of a perfect gas? Why?

No. With saturated steam, the pressure depends solely on the temperature and is independent of volume. Steam is far from a perfect gas.

452. What is meant by the expansion curve of steam?

The curve that represents the relation between the pressures and volumes for the expansion of saturated steam.

453. Why would it require an innumerable variety of expansion curves to represent correctly the relation between the pressures and volumes for the expansion of saturated steam?

A consideration of the effect of water on the expansive action of steam will make it clear that the expansion curves of saturated steam will depend on the quantity of water originally present and the conditions under which expansion takes place.

454. What is the net or effective pressure on the piston? Give an example.

It is the difference between the total pressure of the steam on one side, and the total pressure of the resisting force on the other side of the piston. For example: if the resisting force is the atmospheric pressure, which is 14.7 pounds per square inch, and if the area of the piston is 100 square inches and the absolute pressure of the steam is 80 pounds per square inch, the net pressure on the piston is $(80-14.7) \times 100 = 6530$ pounds.

455. When the net or effective pressure and the piston displacement are known, how may the work done, as the piston moves from one end of the cylinder to the other, be found?

Multiply 144 by the net pressure on the piston in pounds per square inch, and by the volume displaced by the piston expressed in cubic feet. The result will be the work in **foot-pounds.** The same result will be obtained by multiplying the pressure in pounds per square inch by the volume displaced by the piston in cubic inches and dividing the result by 12.

456. How may the net pressure on the piston in pounds per square inch be found? Give an example.

It may be found by subtracting the resisting force in pounds per square inch on one side, from the absolute steam pressure in pounds per square inch on the other side of the piston. For example: if the resisting force is the atmospheric pressure, 14.7 pounds per square inch, and the absolute steam pressure is 80 pounds per square inch, the net pressure per square inch will be $80-14.7 = 65.3$ pounds.

457. How is the piston displacement found?

It is found by multiplying the area of the piston in square feet by the distance in feet moved over by the piston.

458. What is the purpose of a work diagram?

It is to represent the work done by a moving piston. It is similar to the diagrams used to represent the relation between the volumes and pressures of an expanding gas or vapor.

459. When the work done in a given period of time is given in foot-pounds, how may the corresponding horsepower be found?

If the work done is given in foot-pounds per minute, to find the horsepower divide by 33.000; if the work done is given in foot-pounds per second, the horsepower is found by dividing by 550.

460. Abbreviate the term horsepower.

H.P.

461. Define the term indicated horsepower.

The power measured by the use of the indicator is called the **indicated horsepower.**

462. What does the indicated horsepower represent?

It represents the total power developed by the action of the net pressure of the steam on the two sides of the moving piston.

463. Abbreviate the term indicated horsepower.

I. H.P.

464. What is friction horsepower?

Friction horsepower is that part of the indicated horsepower that is absorbed in overcoming the frictional resistance of the moving parts of the engine.

465. When the engine is running light—with no load —how does the friction horsepower compare with the indicated horsepower?

When the engine is running light, all the power developed in the cylinder is absorbed in keeping the engine in motion, and the friction horsepower is equal to the indicated horsepower.

466. In what way does the increase of the load on an engine affect the power absorbed in overcoming engine friction?

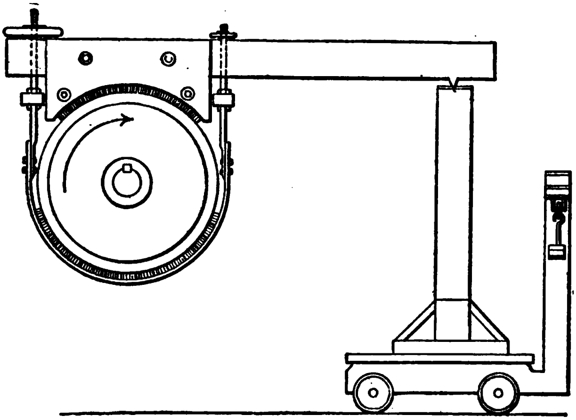
The power absorbed in overcoming **engine friction** will increase as the load on the engine is increased, since the friction between the surfaces of the moving parts of an engine increases with the pressure.

467. What is the net horsepower of an engine?

It is the difference between the indicated and the friction horsepower of that engine.

468. Why is the net horsepower sometimes called (a) the delivered horsepower; (b) the brake horsepower?

(a) The net horsepower is the power the engine delivers through the flywheel or shaft to the belt or the machine driven by it, and is therefore, sometimes, called the **delivered horsepower.** (b) Since the power an engine delivers is often measured by a device known as a **brake,** the net horsepower is also called the **brake horsepower.**



A Brake.

469. What is the mechanical efficiency of an engine?

It is the ratio of the **net horsepower** to the **indicated horsepower**; or it is the percentage of the mechanical energy developed in the cylinder that is utilized in doing useful work.

470. When the indicated and net horsepowers are known, how would you find the mechanical efficiency of an engine?

Divide the net horsepower by the indicated horsepower.

471. What percentage of mechanical efficiency does a good engine usually develop?

From 75 to 90 percent.

472. What is meant by the mean effective pressure, or M. E. P.?

The average pressure urging the piston forward during its entire stroke in one direction, less the average pressure that resists its progress.

473. How may the mean effective pressure, or the M. E. P., be found?

The M. E. P. may be found in three ways: (1) The area of the indicator diagram in square inches may be measured by an instrument called the **planimeter**; the M. E. P. is then found by dividing the area of the diagram in square inches by the length of the diagram in inches and multiplying by the scale of the spring. (2) A special form of planimeter may be used by means of which the M. E. P. may be measured directly. (3) Where a planimeter is not available, the M. E. P. may be found by multiplying the length of the mean ordinate by the scale of the spring.

474. How would you find the indicated horsepower, or the I. H. P. developed by an engine?

Multiply together the mean effective pressure per square inch, the area of the piston in square inches, the length of the stroke in feet, and the number of single strokes per minute. Divide the product by 33.000; the result will be the indicated horsepower of the engine. (In **single acting** engines, only one stroke per revolution does work, and, consequently, the number of strokes per minute to be used in the above rule is the same as the number of revolutions per minute.)

475. What is meant by piston speed?

The total distance traveled by the piston in one minute, is called the **piston speed.**

476. How would you find the piston speed of an engine?

Multiply the stroke in inches by the number of revolutions per minute and divide the product by 6.

477. Give the piston speeds used in modern practice.

The piston speeds used are about as follows: Small stationary engines 300 to 600 ft. per min.; large stationary engines 600 to 1,000 ft. per min.; Corliss engine 400 to 750 ft. per min.; marine engines 200 to 1,200 ft. per min.

478. In calculating the horsepower of an engine, would you make allowance for area of piston rod, and tail rod? Why?

Yes. Because the effective area of the piston is reduced by the sectional area of the piston rod on one side, and the sectional area of the tail rod (if the piston has any) on the other side. To insure the greatest, practicable degree of accuracy, an allowance for the areas of the piston rod and tail rod must be made. The diameter of the cylinder should be measured while it is hot.

479. What is meant by a tail rod?

If the piston rod is continued past the piston so as to pass through the head-end cylinder head, the piston is said to have a **tail rod.**

480. What are dynamometers?

They are instruments for measuring power. They are divided into two main classes: **absorption dynamometers** and **transmission dynamometers.**

481. Describe some form of absorption dynamometer.

The most common form of absorption dynamometer is the **Pronv Brake,** which consists simply of a friction brake designed to absorb power in friction, and thus measure the work done by a motor, or the power given out by a shaft.

482. Describe the use of a transmission dynamometer.

To determine the power required to run the shafting in a mill, a transmission dynamometer is interposed between the shafting and the source of power, and by suitable belt connections the shafting is driven through the dynamometer, from which the power can be determined.

483. How would you determine the size of a simple steam engine to develop a given indicated horsepower?

The diameter of the piston and the length of the stroke constitute the **size** of an engine. Before this data can be determined, the boiler pressure, point of cut-off, and piston speed must be chosen. From the boiler pressure and the point of cut-off the mean effective pressure likely to be realized is then estimated. The area of the piston is then given by the following rule: To find the piston area in square inches, multiply the indicated horsepower by 33.000 and divide by the product of the mean effective pressure and the piston speed in feet per minute. This is for double-acting engines.

Since the piston speed is the product of the number of single strokes and the length of the stroke, the length of the stroke can be found by the following rule: To find the length of the stroke in feet, divide the piston speed by the number of single strokes.

REGULATION AND GOVERNING

484. What is the purpose of a governor?

It is to provide means for controlling the supply of steam admitted to the cylinder, so that the average force acting on the piston will be just great enough to overcome the average resistance. In other words, it is the duty of the governor to keep the speed of the engine practically uniform and to prevent its **racing**, or **running away**, or its slowing down and stopping.

485. What is the duty of the flywheel?

It is the duty of the flywheel to help the engine over the dead centers, when the piston is near the end of the stroke, and the pressure has been reduced by the expansion of the steam. The flywheel also serves as a reservoir for storing the work done in the cylinder when there is a sudden drop in the load on the engine that cannot be immediately taken care of by the governor, or for furnishing a supply of energy to do the work when there is a sudden increase in the load. The flywheel thus aids in preventing too great a change in speed when there is a sudden change in the load.

486. When the speed of an engine is uniform, how can the work done in the cylinder be regulated?

It can be regulated by varying the average net pressure on the piston.

487. How can the average net pressure on the piston be varied?

It can be varied by three different methods: 1. By varying the pressure of the steam admitted to the cylinder; 2. by changing the point of cut-off, so as to vary the ratio of expansion; 3. by varying the back pressure, or the pressure opposing the motion of the piston.

488. Explain the first method of varying the average net pressure on the piston.

The flow of steam to the steam chest is controlled by a valve that regulates the pressure in the steam chest without affecting the expansion of the steam in the cylinder. The valve **throttles** the steam, and this method of governing is, therefore, called **throttling.** The device for automatically controlling the flow of the steam is called a **throttling governor.**

489. What is meant by the term wiredrawing of steam?

When steam has its pressure reduced by flowing through a narrow passage, like a partly closed valve, it is said to be **wiredrawn.**

490. Explain the second and third methods of varying the average net pressure on the piston.

In the second and third methods of governing, the pressure of the steam admitted to the cylinder at the beginning of each stroke is nearly the same, and the work done in the cylinder is varied by controlling the action of the valve so as to cut off the steam supply earlier or later in the stroke. In many cases, the point at which the compression begins is also varied which has the effect of varying the average back pressure, or the resistance to be overcome by the piston. If the cut-off is regulated by hand, as, for example, is the case with the link motion of a locomotive, the engine is said to have an **adjustable cut-off.** If the action of the valve is automatically controlled, the device for regulating the cut-off is called an **automatic cut-off governor.** An engine with an automatic cut-off governor is called an **automatic cut-off engine.**

491. Describe the general principles of a centrifugal governor.

Most steam-engine governors depend for their action on the effect of the centrifugal force, developed in a weight revolving around an axis outside of its center of gravity, in overcoming a varying resisting force. The weight is so suspended that the centrifugal force developed by its rotation is opposed by a variable resistance. When the speed and centrifugal force increase, the weight moves outward and the resistance increases until it balances the increased centrifugal force; when the speed decreases, the centrifugal force becomes less than the resistance and the weight is forced toward the axis; as the weight moves toward the axis, the resistance decreases until it is again balanced by the centrifugal force in the new position.

This motion of the weight is transmitted by a suitable mechanism to the valve that controls the flow of steam to the cylinder.

492. Describe a simple pendulum governor.

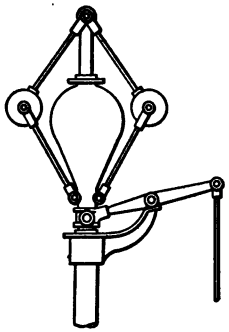
The **simple pendulum governor,** as provided with revolving pendulums, is a form of governor much used on Corliss engines. For the purpose of making the governor symmetrical and preventing the bending action on the spindle that would result from the effect of a single weight, two balls are used. These balls are suspended from a collar that is fastened to and rotates with the spindle of the valve. Links connect the arms, to which the balls are attached, to a collar that turns freely on a sleeve. This sleeve does not rotate, but is free to slide up and down on the spindle. When the balls fly outward, the sleeve is pulled upward by the links and the collar. This motion is transmitted to the valve gear by a connecting rod. To prevent sudden fluctuation of the governor, a rod operates a piston in a cylinder filled with oil. A small opening, either through the piston or through a passage outside of the cylinder, connects the spaces above and below the piston in the cylinder. As the piston moves up or down in the cylinder, the oil flows from one side to the other through the small passage. By regulating the size of the opening, the rate of flow of the oil, and, in consequence, the rate of motion of the piston, can be regulated. This checking device is called a **dashpot.**

493. Is the simple pendulum governor practicable for high speeds? Why?

No. The action of this type of governor is slow in responding to sudden increase in load; the result is that before the governor can move far enough to open the valve and admit the steam required for the greater load, the speed of the engine will drop considerably below normal.

494. Describe the weight pendulum governor.

The **weight-pendulum governor,** also called the **Porter governor,** from the name of its inventor, is a modification of the simple pendulum governor. In this governor, the centrifugal weights are small and their centrifugal force is made comparatively great by running them at a high speed. In addition to their own weight, the balls must lift a large weight, or counterpoise, that is free to slide up and down on the spindle and is lifted by means of links. The counterpoise revolves with the spindle. At its lower end it is fitted with a collar that gives motion to a lever that transmits the motion to the gearing that operates the valve. A lever carries a weight that can be adjusted along the lever so as to change the speed of the engine by a small amount. A dashpot checks any tendency of the governor to fluctuate too rapidly. The governor is driven by a belt from a pulley on the engine shaft to a pulley which drives the spindle by means of a pair of bevel gears. The effect of the counterpoise is to add to the resistance against which the centrifugal force developed by the rotation of the balls must act, without changing the centrifugal force itself, as would be the case if extra weight were added to the balls. The result is that the balls must revolve at a higher speed in order to develop a centrifugal force great enough to overcome the added resistance. The change in the height of the governor for a given change in speed of rotation is also greatly increased. This is called **increasing the sensitiveness of the governor.**



A Weight Pendulum Governor.

495. Describe a spring-loaded governor.

In a **spring-loaded governor**, a spring is used instead of the counterpoise for increasing the resistance opposing the centrifugal force of the revolving weights of a pendulum governor. In the Gardner throttling governor, for instance, a helical spring is enclosed in a case provided with a hand wheel and screw by means of which the amount of compression of the spring, and, in consequence, the resistance, can be varied. By changing the compression of the spring, the speed of the engine can be varied through a wide range. The spindle and flyballs are driven through bevel gears by a belt on a pulley. As the balls fly outward, they force the spindle downward; this operates a lever and compresses the spring, which thus acts to oppose the outward motion of the balls. The motion of the spindle is transmitted to the valve by means of the valve stem that is attached to the lower end of the spindle. The lever is so extended as to provide for attaching a cord or other connection by means of which the speed of the engine can be controlled from a distance. This device, which is much used in connection with engines for driving sawmills, is called a **sawyer's lever.**

496. Describe another form of spring governor.

The **Pickering governor** has three flyballs attached to flat springs. In this governor the resisting force is furnished almost entirely by the resistance of the springs and is but little affected by the weight of the balls. As a means of varying the resistance and the speed of the engine, the governor is provided with a coil spring wound around a spindle that carries a fork. The tension of the spring presses this fork upward against the governor spindle and thus increases the resistance in proportion to the tension, which may be regulated by a worm-wheel and worm, operated by a hand wheel. As the governor balls move outward against the resistance of the springs, they lower the valves and thus partially shut off the steam supply. The two valves are balanced; that is, the pressure on the top of one is balanced by a nearly equal pressure on the lower side of the other; this makes the resistance to their motion very small and makes it possible for the governor to move them easily.

497. Explain some of the advantages of the spring-loaded governor.

The spring of the spring-loaded governor serves nearly the same purpose as the counterpoise of the weighted-pendulum governor. With the **spring-loaded** governor, however, the force opposing the centrifugal effect of the flyballs can be made as great as is desired without the necessity of introducing a heavy weight whose inertia must be overcome, by comparatively small forces, before the governor can respond to a change in speed. With the comparatively light weights of a spring-loaded governor, the momentum of the moving parts is made small in proportion to the forces and resistances to be overcome; this type of governor, therefore, responds more quickly to changes to speed and is much less subject to the tendency to **hunt** or **race.** Another advantage of the spring-loaded governor is the facility with which the speed of the engine can be changed by changing the tension of the spring.

498. It has been stated that the work done in an engine cylinder can be regulated by varying either the point of cut-off or the point of compression, or by varying both of these points together. State one of the most common methods of accomplishing this.

One of the most common methods of varying the point of cut-off or point of compression, or both, is by shifting the eccentric so as to vary its throw and angle of advance.

499. What are the effects of shifting the eccentric?

A general consideration of the effects that can be observed shows that the combined effect of a reduction in the eccentric radius and an increase in the angle of advance is to reduce the travel of the valve and maximum port opening and to make the events of maximum port opening, cut-off, release, and compression occur earlier in the stroke. It also shows that if the eccentric is shifted in such a manner that its center moves in a line perpendicular to the center line of the crank, the lead of the valve will not be changed.

500. By what means is the eccentric automatically shifted?

It is shifted by means of shaft governors.

501. Describe the Erie engine governor.

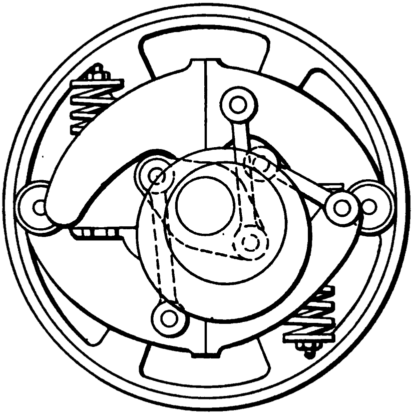
In this type of governor, a frame is keyed to the shaft. Two bell-crank levers are pivoted to this frame. At one end, these levers are enlarged so as to form weights, and at the other ends they are attached to links that connect with the eccentric. The eccentric is slotted so that it may be shifted in such a manner that its center will move in a line perpendicular to the center line of the crank. As the shaft, with the frame and governor revolve, the centrifugal force of the weights tends to cause them to fly outward and so to force the center of the eccentric nearer the center line of the crank. This motion is resisted by the action of a spring, which is of such a length that when put in place it is compressed and exerts a pressure that tends to hold the eccentric in its extreme outer position. This pressure, called the **initial tension** of the spring, resists the centrifugal force of the weights and prevents their moving the eccentric until the engine has reached the desired speed. When the desired speed begins to be exceeded, the centrifugal force of the weights exceeds the resistance of the spring; they then move outward, compress the spring, and shift the center of the eccentric nearer the center line of the crank, thus shortening the stroke of the valve and increasing the angle of advance so as to make the cut-off, release, and compression take place earlier in the stroke. In this way, the work done in the engine cylinder is reduced to such an amount that a further increase in speed is prevented. If the load of the engine increases and the speed begins to decrease, the centrifugal force of the weights is reduced until the force of the spring is sufficient to shift the eccentric in the opposite direction, when enough steam is admitted to the cylinder to do the work. In this way the speed of the engine is kept nearly uniform.

502. In order to give the eccentric center a straight-line path, how is the direction of motion of the eccentric controlled?

The usual method of controlling the direction of motion of the eccentric is to attach it to an arm pivoted either to a disk or to the arm of a wheel keyed to the shaft. The center of the eccentric then moves in an arc whose center is the center of the pin to which the arm is pivoted.

503. Describe the Westinghouse governor.

A disk is attached to the shaft and two weights are pivoted to this disk. The eccentric is attached rigidly to an arm which is pivoted to the disk. The two weights are connected by a long link in such a way that they always move together. A short link connects one of the weights with the eccentric; any motion of the weights is thus transmitted to the eccentric so as to change the position of its center with respect to the center line of the crank. When the weights are in their inner position, the eccentric is in the position of its greatest throw. As the shaft revolves, the centrifugal force of the weights is resisted by the tension of two springs. When the speed becomes great enough to enable the centrifugal force to overcome the resistance of the springs, the weights move outward and shift the eccentric about its pivot until the travel of the valve is adjusted to the work to be done. In this governor, the eccentric lies behind the crank at an angle of 90° minus the angle of advance. The



A Shaft Governor.

reason for setting the eccentric in this position is because an indirect valve is used with this governor. If a direct valve were used, the crankpin would be on the opposite side of the shaft.

504. Explain the effects of inertia of weights on the action of a governor.

The effect of inertia is first to oppose the motion of the weights, then, after they have been set in motion, to carry them beyond the point at which there is equilibrium between their centrifugal force and the resistance. Inertia makes the governor slow to respond to the action of the forces induced by a change in the speed of rotation, and thus permits a considerable change in speed before the governor adjusts itself to the change in load; it also acts to carry the weights beyond the point corresponding to the correct valve opening or eccentric position, and so sets up a series of vibrations, and the governor **hunts** or **races**. In the spring-loaded pendulum governor, inertia is made small by the use of small weights, while the useful forces are made comparatively large by running the governor at a high speed and by using powerful springs; in this way the disturbing effect of inertia is kept from becoming serious. In the shaft governor, however, the speed of rotation is limited to the speed at which the engine may run; it is, therefore, impossible to obtain enough centrifugal force to control the valve properly, without the use of heavy weights, and this, in turn, means a corresponding increase in inertia.

505. Describe an inertia governor.

In the **inertia governor,** the effect of inertia instead as acting as a disturbing force is made to assist the weights in adjusting themselves to changes in speed; such a governor can, therefore, be made to respond very promptly to the slightest variations in load and at the same time be free from a tendency to hunt. The inertia governor used on the McEwen engine will serve to illustrate the principles involved in all governors of this class. A wheel, sometimes called the governor case, is keyed to the engine shaft in the same manner as is an ordinary flywheel. Pivoted to this wheel, by a roller bearing on a pin, is the inerita weight or bar, the two ends of which are hollow; this bar is symmetrical with respect to the center of the pin. A spring is attached at one end to the rim of the wheel and at the other to the bar. One end of the bar is weighted by being partly filled with shot, and as the wheel revolves the centrifugal force of this weight tends to carry it outward; this tendency is resisted by the pull of the spring, the initial tension of which is sufficient to overcome the centrifugal force until the required speed is reached. When the speed begins to exceed that desired, the centrifugal force of the weight throws out that end of the bar; that motion shifts the eccentric pin, which serves the purpose of an eccentric, nearer the center of the shaft, thus shortening the throw of the eccentric and increasing the angle of advance. Up to this point the action of the governor is the same as that of other centrifugal governors. But when the load, and, consequently, the resistance to the turning of the shaft, suddenly drop, the speed of rotation of the shaft and governor wheel quickly begins to increase. The only way in which this increase in the speed of rotation can be imparted to the heavy bar is through the action of the flexible spring. Owing to the weight and length of the bar, its inertia offers considerable resistance to a sudden change in its angular velocity; the result is that the wheel advances faster than the bar, which has the effect of shifting the eccentric pin nearer the center of the shaft and causing cut-off to take place earlier, thus preventing a serious increase in speed before the centrifugal force can act. If the load on the engine is suddenly increased, the speed of the wheel is quickly checked; the resistance of the bar to a sudden change in its speed of rotation causes it to move ahead of the wheel and thus to shift the eccentric pin so as to make the cut-off take place later; in this way enough steam is admitted to the cylinder to meet the demand. Two stops are provided to limit the range of motion of the bar. A dashpot consisting of a cylinder in which a loose-fitting piston works, checks the motion of the bar and prevents too rapid changes in the eccentric position. The centrifugal force of the dashpot piston is counterbalanced by that of a weight on the other end of the piston rod; this prevents the piston from bearing heavily against the walls of its cylinder and reduces friction and wear. The lug to which the spring is attached has three holes, by means of which the lever arm on which the pull of the spring acts can be adjusted. A similar lug provides a means of attaching the spring to the opposite end of the bar. The dashpot may likewise be shifted. In this way the direction of rotation may readily be reversed.

506. Define the term isochronism.

The centrifugal force of a governor's weight increases at the same rate as the distance from the center of gravity of the weight to the axis. The condition of constant ratio between the centrifugal force and the resistance opposed to it is called **isochronism,** and a governor proportioned in such a manner that this condition is fulfilled is called an **isochronous governor.**

507. Why will a perfectly isochronous governor fluctuate rapidly from one extreme position to another?

A perfectly isochronous governor will be too sensitive for any practical use. At the one speed at which there is equilibrium, the weights will stay in any position and will have no control over the steam supply. The slightest change from this speed will have the effect of shifting the weights to one or the other extreme position, and either shut off the steam supply entirely or open the admission valve wide. This will cause rapid fluctuations of the governor from one extreme position to another; the distribution of steam will be most unsatisfactory, and although the variation in speed may be small, the speed of the engine will be constantly changing.

508. What is the effect on the isochronism of a governor caused by the friction of the joints and the inertia of the moving parts?

The friction of the joints and the inertia of the moving parts of a governor disturb the relation between the forces and make perfect isochronism impossible. These resistances, however, do not assist materially in steadying the governor or in preventing violent fluctuations; in fact, they often add to the violence of the fluctuations by resisting the action of the forces until the change in speed is great enough to overcome the added resistance with which they oppose the shifting of the weights in either direction.

509. Describe the isochronous pendulum or crossed-arm governor.

By suspending the balls from crossed arms, the height of the governor, i.e., the vertical distance between the centers of the balls and the point where the center lines of their arms intersect the axis of the spindle, remains nearly constant for any position of the balls, and the condition of isochronism is very nearly fulfilled. By a careful choice of the relation between the length of the arms and the distance of their point of suspension from the axis, the **crossed-arm governor** can be made very sensitive. A number of governors working on this principle have been built, but they have the defect common to all gravity governors of requiring heavy weights in order to be sufficiently powerful, and, in consequence, are subject to the disturbing effects of inertia.

510. Can a spring-loaded governor of either the "revolving-pendulum" or the "shaft-governor" type be made practically isochronous? If so, how?

Yes. By so adjusting the spring that, as the weights fly outward, the resistance of the spring increases at such a rate as to just balance the increase in centrifugal force. Since a perfectly isochronous governor would be too sensitive for practical use, it is usual to adjust the spring so that its resistance will increase somewhat faster than the increase in the centrifugal force. If the spring is adjusted to nearly the condition of isochronism, a change in speed will move the weights too far, and the governor will hunt. If, on the other hand, the resistance of the spring increases at too great a rate, the change in speed required to shift the weights will be excessive and the regulation will be unsatisfactory.

511. Why does friction tend to cause a governor to hunt or race?

Friction resists the motion of the weights in either direction; in consequence, they will not immediately respond to a change in speed that destroys the equilibrium between the centrifugal force and its resistance; the speed will change until the difference is great enough to overcome the frictional resistance, and, since friction is generally less between surfaces in motion than between surfaces at rest with respect to each other, the weights are likely to be shifted too far, thus setting up hunting. These considerations show the importance of governor pivots in which the frictional resistances are small, and of keeping all parts as well lubricated and freely moving as possible.

512. What effect has a dashpot on the action of a governor?

A dashpot has a steadying effect on the action of a governor. Its resistance is very small when the motion is slow; it, therefore, permits the weights to respond promptly to a change in speed. If, however, the motion tends to become rapid, the resistance to the flow of the fluid through the small opening connecting the two ends of the dashpot cylinder acts as an opposing force that prevents the motion from becoming so rapid as to enable the inertia of the weights to carry them too far. The effect of the dashpot may be regulated by varying the size of the opening connecting the two ends of its cylinder.

513. How would you change the speed of an engine controlled by a simple pendulum governor?

A **simple pendulum governor** has a limited range of speed through which it will have a satisfactory control of the valve, and no change in the mass of the weights or in their position on the arms has any effect on the height of the governor, i.e., the position in which it holds the valve for a given speed; owing to these facts, the only method of changing the speed of an engine controlled bv this type of governor is to change the ratio between the diameter of the governor pulley and that of the pulley on the engine shaft.

514. Give a rule for changing the ratio between the governor pulley and the pulley on the engine shaft,

Find the speed at which the engine is running and the diameter of the governor pulley. To find the diameter of the governor pulley for a required speed, multiply the given diameter by the required speed and divide the product by the known speed.

515. How would you change the speed of an engine controlled by a weighted-pendulum governor?

Weighted-pendulum governors are designed to run at a certain speed, and will work best when run at that speed. If they are provided with an adjustable weight, the speed can be varied through a small range either by shifting the weight along the lever or by increasing or diminishing the weight. Shifting the weight nearer the lever or increasing the weight adds to the resistance opposing the action of the centrifugal force and thus increases the speed at which the governor must run for a given height. Shifting the weight in the opposite direction, or making it lighter, decreases the speed. If it is desired to make a considerable change in the speed of the engine with a weighted-pendulum governor, it is best to change the size of the governor pulley.

516. How would you change the speed of an engine controlled by a spring-loaded pendulum governor?

On account of the facility with which the resistance to centrifugal force can be varied by varying the tension of the spring, a considerable range in speed may be obtained with most spring-loaded pendulum governors without the necessity of changing the size of the governor pulley. Changes in the tension of the spring, however, have an effect on the sensitiveness of the governor; with a certain tension and speed, the relation between the centrifugal force of the weights and the resistance offered by the spring will give the most satisfactory results obtainable, and any variation from this will tend either to reduce the sensitiveness or to make the sensitiveness so great that the governor becomes unstable. For this reason, it is always desirable to run the governor as nearly at the speed for which it was designed as is practicable, and to use a combination of pulleys that will secure this speed. If it is desired to make a considerable permanent change in the speed of the engine, such change should be made by changing the size of governor pulley and not by changing the tension of the spring.

517. How would you adjust the sensitiveness of a shaft governor?

If the spring of a governor is so adjusted that its deflection is proportional to the distance of the center of gravity of the weights from the center of the shaft, the condition of isochronism will be fulfilled, and the governor will be too sensitive. To make the governor less sensitive, the spring must be so adjusted that its deflection for a given position of the weights is less, proportionally, than the distance of the center of gravity of the weights from the center of the shaft. In accordance with these principles the following rules for adjusting the spring are readily deduced: (1) To increase the sensitiveness of the governor, increase the initial tension of the spring. (2) To make the governor less sensitive, reduce the initial tension of the spring.

518. How would you change the speed of an engine controlled by a shaft governor?

In order to change the speed of an engine controlled by a shaft governor it is necessary to change either the centrifugal force of the weights or the resistance of the springs. But any change from a certain initial tension of the springs will result either in making the governor sluggish or in making it too sensitive. It follows, therefore, that a change in speed must be brought about by a change in the centrifugal force of the weights.

519. Give a rule for changing the speed of an engine controlled by a shaft governor.

To increase the speed of an engine with a shaft governor, use lighter weights. To reduce the speed of an engine with a shaft governor, use heavier weights.

520. Describe the governor with adjustable weights and spring attachments.

Many governors have been made in which the weights and the points of attachment of the springs are adjustable along the arms by which they are connected to the pivots. This construction makes it possible to change the relative effects of the centrifugal force of the weights and the tension of the springs by changing the lengths of their lever arms with respect to the center of the pivot; the speed of the engine can thus be changed without changing the mass of the weights.

521. Give a rule for changing the speed of an engine with a governor having adjustable weights or spring attachments.

To reduce the speed of the engine, shift the weights farther from the pivot, or shift the spring connection nearer the pivot; to increase the speed of the engine, shift the weights nearer the pivot, or shift the spring connection farther from the pivot. The amount of variation in speed that can be obtained by these adjustments will generally be small; if a greater variation is needed, it must be made by changing the mass of the weights in accordance with the rule given in Ans. 519.

522. What conditions must be fulfilled in order to make a governor perfectly isochronous?

Considerable force is required to overcome the friction of the valves and valve gearing of most engines; the inertia of the valve and connections must also be overcome. The governor must be powerful enough to enable it to exert the force required to overcome these resistances, and to adjust itself promptly to small changes in speed; it must respond to changes in speed with the greatest of freedom, but it must not be seriously affected by great variation in the force required to move the valve at different parts of the stroke. The fulfillment of these conditions makes necessary the use of heavy weights and powerful springs, with the result that heavy pressures are developed at the pivots. In order that the friction due to these pressures may not become serious, it is necessary to provide special means for securing good lubrication of the pivots, or to use bearings that will work freely without lubrication. In the later type of governors, particularly those of the inertia type, the number of joints has been reduced to a minimum and roller bearings have been substituted for plain bearings.

The roller bearings require no lubrication and the governors will work with but little attention. Knife-edge bearings are also used with excellent results in those positions where the pressures are always in the same direction. If the joints are not properly constructed and lubricated, the excessive friction will soon greatly reduce the promptness with which the governor will respond to changes in speed and it will tend to hunt.

523. What is a self-locking governor?

In order to prevent the varying force required to drive the valve at different parts of its stroke from disturbing the governor weights, a number of so-called **self-locking** governors have been built. In these governors, the motion of the weights is transmitted to the eccentric through a self-locking mechanism; that is, a mechanism like the screw or wedge, which will enable the force exerted by the weights to move the eccentric, but will not permit a force acting on the eccentric to affect the weights. A disadvantage of governors of this type is that the frictional resistances, especially when lubrication is not attended to with the greatest care, are excessive; they are, therefore, likely to be sluggish and unsteady. The disturbing effects of friction often produce more serious results than would have been developed by the forces that the self-locking mechanism is designed to overcome.

VALVE GEARS.

524. How are valve gears generally classified?

Valve gears are classified in a variety of ways, depending partly on their type and partly on the kind of service for which they are used. The most common terms used to denote the different types and classes of service are the following: **Fixed cut-off gears, variable cut-off gears, positive motion gears, cam gears, releasing gears,** or **trip gears, reversing gears.** Valve gears are also classified in accordance with the number of valves used. The leading divisions are **single valve, double valve,** and **four valve.**

525. Describe the fixed cut-off gears.

In this type the motion of the valve does not vary with the amount of work to be done in the cylinder. With a given setting of the valve, cut-off is constant. A plain slide-valve engine is the most familiar example of an engine fitted with a fixed cut-off gear. With it, the points of admission, cut-off, release, and compression do not vary.

526. Describe the variable cut-off gears.

Under this head are included all those gears in which the amount of work done in the cylinder can be regulated while the engine is in operation by varying the motion of the valve so as to change the point of cut-off. If the motion of the valve is controlled automatically by some form of governor, a variable cut-off gear becomes an **automatic cut-off gear.**

527. Describe the positive motion gears.

Positive motion gears are those in which the valve is directly controlled by the eccentric and governing mechanism throughout its whole range of motion.

528. Describe the cam gear and give some of its advantages and disadvantages.

Cam gears consist of a set of cams, one for each valve, on a shaft that is usually driven by means of gears from the main shaft, although the cams are often placed on the main shaft itself. These gears are most often used in conjunction with poppet valves. The cams are so formed and set on the shaft that each will open and close its valve at the proper time. Since it is possible to give the cam such a form as will enable it to open and close each valve quickly at any desired point in the stroke, the steam distribution can be made almost perfect with this type of gear. At anything above very moderate speeds, however, the sudden striking of the tappets or rollers on the cams makes a great deal of noise and the action of the gearing is unsatisfactory.

529. Describe releasing gears, or trip gears.

These gears vary the point of cut-off by releasing the admission valve from the control of the eccentric, and thus permitting it to be closed quickly by some other device, usually a spring or dashpot. The Corliss valve gear is the most familiar type of **releasing gear.**

530. Describe reversing gears.

Reversing gears are used to reverse the direction of motion of the engine; in most cases they may also be used to vary the point of cut-off; hence, most reversing gears are also variable cut-off gears. There are two principal types of reversing gears, the **link motion** and **radial** gears.

531. Name the leading types of valves used to control the distribution of steam to the engine cylinder.

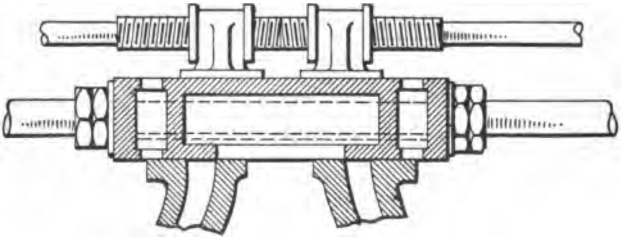
The leading types are **slide valves, rotary valves,** and **poppet valves.**

532. What is the purpose and operation of the expansion valve, or cut-off valve?

In order to extend the range of cut-off beyond that which may be obtained with the plain slide valve driven by a fixed eccentric, and at the same time not to affect the events of admission, release, and compression, various types of auxiliary valve, generally known as **expansion valves,** or **cut-off valves,** have been designed for use in conjunction with the plain slide valve. These auxiliary valves are generally driven by a separate eccentric; their sole purpose is to stop the flow of steam to the cylinder at the desired point in the stroke, leaving the other features of steam distribution to be controlled by the main valve in the usual manner. Since the point of cut-off is the only event controlled by the auxiliary valve, any change in the proportions of this valve or in the position of its eccentric that will secure the desired change in cut-off may be made without affecting the other events in steam distribution; consequently, the point at which the auxiliary valve cuts off the supply of steam may be varied in any convenient way.

533. Give a general description of the cut-off, or expansion valve, and its application.

The main valve is driven by a fixed eccentric in exactly the same manner as in the plain slide valve engine. This valve is given such proportions as will secure the desired points of admission, release, and compression, care being taken that the lap is such that it will not cut off steam earlier in the stroke than the latest point at which it may be desired to have cut-off occur, usually about ¾ stroke. The main valve is located in a section of the steam chest that is separated from the remainder by a plate or partition. This partition has ports or openings that form passages connecting the two chambers, and it also forms the valve seat of the auxiliary valve. The auxiliary valve has ports. It is driven from the main shaft by an auxiliary eccentric. When it is in the mid-position, the ports are open and allow steam to fill the chamber around the main valve. As the auxiliary valve moves either way from the mid-position, it covers the ports and so shuts off the supply of steam from the main



Cut-off, or Expansion Valve.

valve. The main valve is set in exactly the same manner as any plain slide valve. The auxiliary valve must be so proportioned and set that it will open the ports as soon as or before the main valve opens the main port, but they must not be reopened before cut-off occurs with the main valve, otherwise steam will be readmitted to the cylinder and the effect of cut-off will be destroyed. The point of cut-off may be varied by changing either the eccentricity or the angle of advance of the auxiliary eccentric, the latter being the more common method. A disadvantage of this type of expension valve is that when cut-off takes place, the space in the main-valve chamber is filled with steam. This has the effect of increasing the clearance space during the period of expansion, and thus destroys some of the benefits derived from the earlier cut-off. On account of these limitations and disadvantages, this simple form of expansion valve is but little used to-day. This is a very simple application of the **cut-off,** or **expansion** valve. There are, however, other type which are greatly improved and are free from most of its disadvantages.

534. What are the disadvantages of a plain D slide valve when used on an automatic cut-off engine?

The action of a shaft governor is materially affected by the force required to drive the valve; **a plain D solid valve,** requiring as it does a great driving force, not only absorbs a considerable proportion of the power of the engine, but it has a disturbing effect on the action of the governor that, especially with large engines, becomes so serious as to make the use of this type of valve with shaft governors impracticable. When used in conjunction with a shaft governor that varies the throw of the eccentric, the plain slide valve has another defect that is not overcome by the mere process of balancing. This defect is that the reduced travel of the valve consequent on the short throw of the eccentric at early cut-off has the effect of greatly restricting the port opening. At high speed, such a reduction in port opening causes an imperfect filling of the cylinder with live steam. This difficulty can be largely overcome by increasing the travel of the valve so as to give it a considerable amount of **overtravel** for late cut-offs. (By overtravel is meant that the valve is given a travel greater than is required to give a full opening of the steam ports.) To provide for the overtravel, the central chamber of the valve and the bridges between the steam and exhaust ports must be made wider; this means a larger and heavier valve. Giving the valve overtravel thus involves an increase in the travel of the valve and in its weight, both of which add to the power required to move it. Once during each stroke the heavy valve must also be started from rest and given a velocity that becomes greater as the distance through which the valve must move is increased; to overcome the inertia of the valve, a very considerable force is required, and this force, which must act through the medium of the governor, and in consequence tends to disturb the governor action, is increased by the attempt to secure a liberal port opening by means of an increase in the valve travel. Several designs for shaft-governor engines secure an increased port opening by the use of **multiple-ported** valves, in which steam enters the cylinder through two or more passages. While the travel of the valve may be reduced by this means, its size and weight are generally increased, and this neutralizes the advantage of short travel to a considerable degree.

535. State the advantages and disadvantages of the piston valve.

The **piston valve** is one of the lightest and most perfectly balanced types that has yet been devised, and it is readily made double ported. It has, however, several features that have restricted its use to a very great extent. Unless it is provided with some form of packing, there is no means of adjustment to provide for wear; consequently, it soon becomes leaky and wastes steam badly. In vertical engines, where the weight of the valve is not supported by the seat, the wear is not so serious, and there are many cases of such engines in which piston valves with no packing (except grooves in which water collects) have given the best of service. In a horizontal engine, however, the weight of the valve invariably wears the lower part of the seat and destroys its circular form. Packing rings of some form must here be provided or the valve will soon leak. In some cases the valve seat consists of a bushing that can easily be removed when worn; in order that a good fit between valve and bushing may be secured, it will generally be necessary to renew the valve as well as the bushing, or to fit the old valve and the new bushing to each other. The long ports required to surround the piston valve make the clearance large. This type of valve as generally constructed offers no relief to water that may be caught in the compression space after the exhaust port closes.

536. Describe the flat pressure-plate valve.

The **flat pressure-plate valve** is a type that has many of the advantages of the piston valve and at the same time overcomes some of its faults. With minor modifications, it is used in a great number of shaft-governor engines. The valve consists of a thin rectangular casting with openings or ports through it for the passage of live and exhaust steam to and from the cylinder. It works between the face of the valve seat and a similar face formed by a heavy pressure plate. The pressure plate is separated from the valve seat by strips that are made just enough thicker than the valve to permit the valve to slide freely between the pressure plate and the valve seat. When the engine is working, the pressure plate is held in place against two strips by the steam pressure; when steam is shut off, a spring prevents the plate from falling away from its position against the strips. This construction permits the valve and pressure plate to act as a relief valve for the escape of water from the cylinder; an excessive pressure in the cylinder will lift the valve and plate and compress the spring. The danger of breakage from water in the cylinder is thus somewhat reduced; it is not, however, a perfect protection; with quick rotative speeds, the pressure often becomes great enough to damage the engine seriously before water can be forced out through the ports and can overcome the inertia of the valve and pressure plate.

537. What advantage has the flat-pressure plate valve over the piston valve?

An advantage of the pressure-plate valve over the piston valve is that in horizontal engines the wear due to the weight of the valve, coming as it does on the lower edge and strip, does not affect the tightness of the valve. Another advantage is that when the valve wears so as to allow steam to leak between it and the faces of the valve seat and pressure plate, the strips can be planed or scraped so as to overcome this wear; this operation, however, requires considerable care and skill. If the valve or the faces between which it works are unevenly worn, it will be necessary to scrape them to a new surface; this is a tedious and somewhat difficult task with the facilities available in most engine rooms.

538. How can a leaky slide valve be detected?

To detect a leaky slide valve turn the engine until the slide valve is in the middle of its stroke, block the flywheel, open the relief cocks, or the indicator taps, and admit steam into the steam chest. A steady escape of steam through the relief cocks, or the indicator taps, will indicate a leaky slide valve.

539. With either piston valves or pressure-plate valves, what precaution is required when starting the engine?

The precaution required is to admit steam to the steam chest slowly so as to warm the valve and its seat gradually and evenly; if steam is turned on too rapidly, there is danger that the valve will be heated faster than its seat and that it will swell so much as to bind or seize in its seat and break some part of the valve gearing.

540. Describe some form of self-adjusting balanced valve and its advantages.

Many of the faults of other valves are overcome by the use of **self-adjusting balanced valves,** of which there are several types. In one, the pressure plate is held against the back of the valve and the valve against its seat by a certain amount of unbalanced steam pressure. In another form that has been much used on locomotives and on some types of stationary engines, although not to any great extent on shaft-governor engines, the back of the valve is fitted with packing rings or strips that bear against a fixed pressure plate and prevent live steam from reaching the space between the pressure plate and the back of the valve. Still another form of self-adjusting balanced valve is made of two separate pieces, one working telescopically in the other, the joint between the two being kept steam-tight by packing rings. Each part of the valve bears against its own seat and controls the flow of steam through its own set of ports. Live steam enters the chamber formed by the combination of the two parts, through the opening in the upper wall of the steam chest, and passes through the ports to the cylinder; the exhaust is discharged into the steam chest around the outside edges. The valve is thus **indirect** and the combination of the two parts, each with its separate ports, secures a **double-ported** effect for both steam and exhaust. The two parts of the valve are held against their respective seats by the pressure of the steam in the chamber (formed by the combination of the two parts); the action of this pressure tending to separate the parts. By this arrangement, the valve automatically follows up any wear, and if the working faces are kept in good working order it will always be tight. It is not quite as perfectly balanced as the piston valve or the flat-pressure plate valve, and its weight is probably a little greater than that of either of these types. With it, the ports are necessarily long and the clearance space is large; in this respect it is probably to be compared with the piston valve.

541. **What are the most characteristic features of the Corliss valve gear?**

They are: (1) The four **oscillating valves,** two of which are placed at each end of the cylinder—one controlling the admission of the steam and called the admission valve, the other controlling the liberation of the expanded steam, and called the exhaust valve. (2) The **wristplate,** which is an oscillating plate, disk, or lever actuated by the eccentric from the main shaft and in turn communicating motion to the four valves. (3) The **releasing mechanism,** of which the governor forms a part. This disconnects an admission valve from the wristplate when the supply of steam is to be discontinued through its port. (4) The **closing appa-**

ratus. This, immediately upon the release of an admission valve, brings the valve back to its closing position.

542. Are all Corliss valve gears built alike?

No. Corliss valve gears have been built in a great variety of forms, differing from one another principally in the details of the releasing mechanism and in minor features of construction. These gears, however, all operate on the same general principles, and when one is understood there will be little difficulty in understanding any of the others.

543. Describe the general construction of one of the forms of the Corliss cylinder and valves.

There are four distinct valves. Two of these admit steam to the crank end and head end of the cylinder, respectively. They are in communication with the steam chest and steam pipe, and are called the **steam-valves.** The other two valves communicate with the exhaust chamber and exhaust pipe. These valves allow the steam to exhaust from the crank end and head end of the cylinder, respectively, and are called the **exhaust valves.** The valve faces are cylindrical in form, and the valves rotate on circular valve seats. Each valve extends across the cylinder; that is, the length of the valve is about equal to the cylinder diameter. The steam valves open their ports when their faces move away from the center of cylinder towards the heads. The steam and exhaust valves open but one passage for the flow of the steam to and from the cylinder, and are, therefore, **single-ported** valves.

544. Are all Corliss valves made single-ported?

No. There are methods of construction by means of which the valves are all made **double-ported.** The steam valves in these cases open their ports by rotating in the opposite direction to that in which the **single-ported** valves rotate; that is, to open the ports, the valve faces move **away** from the heads toward the center of the cylinder. The form of the valves is such that steam flows past two edges. This construction provides a sufficient port opening with a much smaller valve movement, and greatly improves the distribution of steam to the cylinder.

545. Describe the mechanism for operating the Corliss valves.

One of the most familiar forms of such mechanism may be described as follows: The steam valves are driven by spindles, called the steam-valve **stems**, and the exhaust valves by spindles called the exhaust-valve **stems**; the center lines of these spindles coincide with the center lines of their respective valves. To the steam-valve stems and the exhaust-valve stems cranks are keyed. A disk, called the **wristplate**, is made to rock on a stud by a rod, called the **wristplate rod**, which takes its motion from a **rocker-arm** that in turn is driven through an eccentric rod by an eccentric placed on the main shaft. To the wristplate are connected four **valve-rods.** As the plate rocks, these valve rods are given a to-and-fro motion. The exhaust-valve rods are connected directly to the cranks of the exhaust valves. The motion of the plate is thus communicated to the exhaust valves, causing them to open and shut the exhaust ports at the proper time. The steam-valve rods, however, are not connected directly with the cranks of the steam valves, but with bell-cranks, called the **admission cranks.** These bell-cranks can rotate around the valve stems, not being connected rigidly to them. The bell-cranks carry **disengaging links**, which participate in the rocking motion given to the bell-cranks by the steam-valve rods. These disengaging links hook on to **blocks** rigidly fastened to the cranks keyed to the valve-stems. Consequently, when the bell-cranks, and with them the disengaging links, are rotated by the motion of the valve rods, the valve stem cranks are forced to move with them. This motion of the crank rotates the valve and admits steam to the cylinder.

546. Describe the cut-off mechanism of the Corliss valve gear.

On the steam-valve stems are collars, called the **trip collars**, which are free to rotate on the stems. Each collar is provided with an arm to which is attached a rod, called a **governor rod**, that leads to the governor. Each collar also has a projection, called a **trip**, that lies in the same plane as the arms of the disengaging

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hooks. Considering now the head-end admission valve, let us imagine the wristplate to be rotating towards the left; this motion will be transmitted by the steam-valve rod to the bell-crank and will carry the link and disengaging hook in an upward direction, thus lifting the block and rotating the crank to which the block is attached. This crank, being keyed to the valve-stem, turns with this stem and so opens the valve, the direction of motion of the valve face being from the head end toward the center of the cylinder. As the disengaging link is lifted, its arm strikes the trip on the collar; this swings the disengaging link about the pin by means of which it is pivoted to the bell-crank, and thus detaches the hook from the block and stops the opening motion of the valve. To the cranks keyed to the steam-valve stems are attached rods leading to the pistons of **dashpots.** When the crank is rotated by the upward motion of the block, the dashpot rod attached to it lifts the piston in the dashpot and creates a partial vacuum in the space below the piston. When the block is released from the hook on the disengaging link, the pressure of the atmosphere forces the dashpot piston downward, thus quickly closing the valve and cutting off the supply of steam to that end of the cylinder. When the wristplate moves in the opposite direction to that just considered, the disengaging hook is moved downward until it again engages the block and the motion above described is ready to be repeated upon the reversal of the wristplate. The action of the crank-end admission valve is precisely the same as that for the head-end, except that it is opened when the wristplate rotates toward the right.

547. **Explain how the motion imparted to the valves of a Corliss valve gear by a given angular motion of the wristplate varies, and how this variation is made to improve the action of the valves.**

The wristplate is so made as to modify the effect of the eccentric motion in such a way that the motion of the valves is considerably improved. The motion imparted to the valves for a given angular motion of the wristplate varies through wide limits. When the wristplate pin moves through a given distance from its extreme positions, the steam valve moves through a much shorter distance; when, however, the wrist-plate pin reaches the middle of its motion, the motion imparted to the valve is relatively very rapid. As the crank passes its dead center, the speed of the valve increases rapidly. This has the effect of opening the valve rapidly just as the piston reaches the end of its stroke, thus permitting a free admission of steam. The valve continues to open at a good rate of speed until it is closed by the releasing gear or until the eccentric reaches its extreme-throw position. By comparing the motion of the steam and exhaust valves, it is seen that when the steam valve is nearly at rest the motion of the exhaust valve is most rapid. The exhaust valve was opened wide before the piston began its stroke, and rapid closure occurs when compression begins. Following the point of exhaust closure, the motion of the valve is very slow until the piston again approaches the opposite end of its stroke, where release is to take place.

548. How can the point of cut-off be varied?

The point at which the blocks are released from the hook on the disengaging links, and, in consequence, the point at which cut-off takes place, depends on the position of the trips. The position of the trips can be changed by swinging the collars. The position of the collars is generally controlled by a pendulum governor acting through governor rods. When the rods are moved in one direction, the trips are lowered and cut-off takes place earlier; when the rods are moved in the opposite direction, the trips are raised and cut-off takes place later.

549. Explain how the Corliss valve will operate when the engine is working under (a) a light and (b) a heavy load.

(a) When the engine is working under a light load, the governor collar is kept in such position by the governor that the cut-off trip releases the hook early in its motion, while (b) for a heavier load the reverse is the case. As the motion of the hook is an oscillating one, it can evidently not be released by the trip after it has started its return stroke. If the load on the engine becomes so heavy that the governor moves the

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trip so far that it will not be struck by the hook before the reverse motion of the hook begins, release of the hook will not take place at all. In this case the admission valve will be closed as if positively connected to the admission crank, the same as the exhaust valves.

550. **Explain the action of the dashpot of the Corliss valve-gear.**

The dashpot consists of two concentric cylinders of different diameters. In the upper and larger of these cylinders there is fitted a piston having a central projecting portion that extends downward and forms a plunger, which plunger fits the lower and smaller cylinder. The upper cylinder has an opening in its end that may be regulated by a valve or cock. This opening is placed so as to be a short distance above the lower edge of the piston when it is in its lowest position; it allows a small quantity of air to enter as the piston rises, and this air checks the downward motion to an extent depending on the amount of opening of the valve. After the lower edge of the piston descends until the opening is covered, the further escape of air is prevented and the air remaining in the cylinder acts as a cushion that prevents the piston from striking the bottom too violently.

551. **If the piston strikes the bottom of the cylinder of the dashpot, or slams, what does it indicate and how can it be remedied?**

If the piston **slams,** it indicates that so much air escapes that not enough is caught under the piston to cushion it properly. This difficulty can be remedied by reducing the opening of the cock.

552. **Why is it advisable to provide the lower cylinder with a check-valve?**

The lower cylinder is made as nearly air-tight as possible; a check-valve should be provided to permit of the escape of any air that may leak in around the plunger.

553. **How may the hissing sound, made by the escape of air from the opening in the side of the dashpot cylinder, be prevented?**

This hissing sound may be prevented by connecting the opening to a pipe that leads outside of the engine room. Some dashpots are made with an air chamber that forms a reservoir from which air is drawn by the rising piston and into which the air is discharged again as the piston descends. This prevents the hissing sound without the necessity of using the pipe.

554. Explain the necessity of lead and lap on Corliss valves.

In any valve gear, the motion of which is derived from the action of an eccentric set at 90° ahead of the crank, the crank will be on its center when the eccentric is at half throw and the eccentric will arrive at its greatest throw, and the opening motion of the valve will cease, when the crank is at half stroke. With releasing gears, like the Corliss, the releasing mechanism must operate, if at all, before this point in the eccentric travel is reached; otherwise, the valve will begin to close positively, and at a speed governed by the eccentric on its return stroke. The Corliss valve gear, when properly constructed, closes the valve positively before the end of the stroke, in case the trip does not act or the dashpot fails to close it; this fact does not seem to be generally known. It follows, then, that when the releasing mechanism does not operate, a steam valve set edge to edge with the port opening is closed at the moment the piston reaches the end of its stroke. The exhaust valve on that end of the cylinder opens at the same moment, and there is a tendency to blow through. On the other end of the cylinder, the exhaust valve closes and the steam valve opens, also at precisely the same moment, giving the steam another chance to blow through. It is essential, then, that the steam valve shall have a definite advance in its closing movements, relative to the opening of the exhaust valve, in order that it may have a safe working lap before the exhaust port is opened, and that it may not open until after the exhaust valve has closed. The exhaust valves must also have an advance relative to the piston movement, in order that there may be prompt release, and that they may close on the end toward which the piston is moving before it arrives at the end of its stroke. This is necessary to produce sufficient compression to check the motion of the reciprocating parts of the engine.

555. What effect has lead on Corliss valves, as derived from the advance of the eccentric?

By setting the eccentric at an angle of more than 90° ahead of the crank, we get an earlier opening and an earlier closing of all the valves, relative to the piston motion. But the same amount of lead is not needed for all of the valves, relatively more lead being required on the exhaust valves so that they may close early and thus give sufficient compression. But this does not help us to get the steam valve closed previous to the opening of the exhaust valve nor the exhaust closed before admission of steam. The effect, then, of **lead**, as derived from the advance of the eccentric to an angle of more than 90° from the crank, is to hasten both the opening and the closing of all of the valves, as compared with the motion of the piston; therefore, lead hastens cut-off.and limits its range.

556. Explain the effect of lap on a valve, and the amount of lap required.

The effect of **lap** on a valve is to hasten its closing and to retard its opening. Here, again, cut-off is hastened and its range limited. From this it will be seen that, when a single wristplate is used, there are conflicting conditions in the setting of valves between which a compromise must be effected. No definite rule can be given by which the amount of lap for a valve can be determined. It depends somewhat on the design of the valve and its relative proportions; also on the conditions under which the engine is to work. In all cases the **lap** increases with the size of the cylinder. (The makers of the engine will furnish a reliable guide as to the amount of lap to be given to valves on different sizes of engines.)

557. Describe a method of centering a rocker-arm and wristplate on a Corliss valve gear.

In most cases, there will be found three marks on the wristplate bracket and another mark on the hub of the wristplate, by means of which the wristplate may be centered. The marks are so located that the mark on the hub is opposite the center mark on the wristplate bracket when the wristplate is at its center of motion. At the two extremes of motion the mark on the hub is opposite either one of the two end marks on the wristplate bracket.

558. How would you ascertain whether the eccentric and carrier rods, on a Corliss valve gear, have proper adjustment, relative to the motion of the wristplate?

To do this, rotate the eccentric on its shaft, having the eccentric rod connected and the carrier rod hooked over on the wristplate; then notice whether or not the rocker-arm is the same distance in its extreme travel each way from a plumb line let fall through the center of its pin. If it is not, make it so by adjusting the length of the eccentric rod. Next, see if the mark on the wristplate hub agrees with those on the bracket at full throw each way; if not, the remedy is to change the length of the carrier rod until there is perfect agreement. Having tested the marks temporarily, secure the wristplate at its center of motion.

559. How would you adjust the lap on Corliss valves?

Upon removing the back bonnets, or caps, from the ends of the valve chambers, so that the rear ends of the valves are exposed, a mark will usually be found on each face of the valve ports, showing the location and width of the port openings in relation to the cylinder. Upon the ends of the valves, marks in line with the opening edges of the valves will also be found. If these marks are missing, the valves will have to be removed to locate the port openings and the opening edges of the valves. Next, determine (from tables furnished by the makers) the lap for the steam valves and the opening to be given the exhaust valves. By lengthening or shortening the rods leading from the wristplate to the valve arms, bring the opening edges of the valves to positions corresponding with the desired lap or opening. While making these adjustments, it is essential that the steam latch shall be hooked on the stud. If a record is kept of how much the valve moves at one turn of the adjusting nut on the rod, future adjustments may be made without the removal of the bonnets.

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560. How would you adjust the lead on Corliss valves?

First, set the engine exactly on its center; then place all the valves in their proper positions when the wrist plate is at its center of movement. Next, with the carrier rod hooked on the wristplate stud, revolve the eccentric on the shaft in the direction in which the engine is to run, until it is at an angle greater than 90° ahead of the crank or until the steam valve on the end at which the piston stands is just beginning to open. In this position the eccentric must be secured to the shaft. Then turn the engine to the other center and see if the steam valve on that end has the same amount of opening as the other had. It should and will have the same amount of opening if all adjustments have been carefully made.

561. How would you adjust the governor on a Corliss engine?

To adjust the governor, block it so that the balls stand in the position they would assume at normal speed (about mid-position) and fasten the reach-rod lever at right angles to a line midway between the reach-rods. Now turn the engine to the point at which cut-off should occur (usually about ⅕ stroke) and adjust the reach rod for that end, so the valve will trip at that point. The valve and the reach rod for the other end of the cylinder must be adjusted in a like manner. Now, lower the governor to the lowest position and observe that the cut-off mechanism does not work, but allows steam to be taken during the full stroke of the piston.

562. How would you regulate the sensitiveness of the governor?

By varying the amount of opening between the two ends of the dashpot cylinder.

563. How would you determine the point of ⅕ stroke?

To do this, mark the length of stroke on the crosshead guides and measure off ⅕ of this from each end.

564. In adjusting the valve gear, what particular attention should be given the governor dashpot?

The dashpot rods must have such a length that the steam arm will be in a position where the hook will surely hook on when the dashpot plunger is home. If the dashpot rod is too short, the latch will not hook.

565. Why is it advisable to mark every position on the valve gear?

With every position marked, one can tell at a glance if any adjustments have been disturbed.

566. Why are Corliss valve gears sometimes made with two eccentrics?

In order to secure a satisfactory steam distribution, when the steam and exhaust valves of a Corliss engine are both driven by the same eccentric, it is necessary to give the eccentric a certain angle of advance. The releasing gear cannot act on the valves after the eccentric has passed its extreme throw position. The result of these conditions is that with a single eccentric the releasing gear must act before the piston has passed through a certain fraction of its stroke. This fraction is always less than ½ and is often little more than ⅜. If the load on the engine is so heavy that cut-off does not take place before this fraction of the stroke has been completed, the steam valves will not be under the control of the governor, but will be closed only by the action of the eccentric. The range at which cut-off can be controlled by the governor can be considerably extended by the use of two eccentrics and wristplates—one for the steam valves and one for the exhaust. The exhaust eccentric can then be given the angular advance required by the conditions, while the steam valves may be made to open early enough to secure the desired lead, even though the steam eccentric is set without any angular advance, or at an angle of less than 90° with the crank. The steam eccentric thus reaches its extreme throw position later in the stroke, and the range within which cut-off is controlled by the governor is correspondingly lengthened.

567. If two eccentrics are used on a Corliss valve gear, what is the effect on the opening of the steam valves when the steam eccentric is set too near the crank position?

By setting the steam eccentric sufficiently near the crank, the range of cut-off with a double eccentric may be extended nearly or quite to full stroke. Such a range, however, is not desirable; it is not economical to use an engine under a load that makes it necessary for steam to follow the piston at boiler pressure for such a large part of the stroke; and, in addition, an attempt to secure a long range of cut-off by setting the eccentric back near to the crank position will cause the steam valves to open very slowly at the beginning of the stroke, thus producing wiredrawing of the steam and reducing the economy when working under normal loads. Satisfactory results can be obtained with the eccentric set at an angle of as little as 81° with the crank, 9° back of the 90° position; this provides for an extreme range of cut-off of about 7/10 stroke.

568. In designing and adjusting the cut-off gear with a double eccentric motion, what precaution must be observed relative to the steam and exhaust valves?

It is important to make sure that the steam valve for each end of the cylinder shall always be closed by the action of the releasing mechanism before the exhaust valve for that end opens. If this precaution is not observed, there will be danger that with a heavy load the steam and exhaust valves for one end of the cylinder will both be open at the same time, thus allowing steam to blow from the steam chest directly through the cylinder into the exhaust.

569. In case the governor belt should break, what is there on a Corliss valve gear to prevent the engine from running away?

Most modern Corliss valve gears are fitted with a **safety stop** that will prevent the running away of the engine. In case the governor belt should break, this safety device will prevent the steam valves from hooking on when the governor stops. When the engine is about to be started, this safety device would prevent the starting of the engine, as the steam valves cannot operate; therefore a collar is usually fitted to the governor by means of which it can be raised sufficiently to allow the steam valves to hook on in starting. As soon as the engine is running, this collar must be lowered again so as to render the safety stop operative.

570. What are some of the advantages of the high-speed Corliss valve gear as compared with the ordinary Corliss gear?

In order to secure the advantages of the four oscillating valves and the wristplate motion of the Corliss gear without the attendant disadvantages of the restricted speed of revolution that is imposed by the releasing gear, and also to secure the positive valve motion and the superior degree of regulation that can be obtained with shaft governors, a number of engines have been designed with Corliss valves and the wristplate, driven by a shifting eccentric controlled by a shaft governor. Since it is often desirable to keep the release and compression constant, some of these engines use two eccentrics. One of the eccentrics drives the steam valves; it is controlled by the governor so as to regulate the amount of valve opening and the point of cut-off in practically the same manner as with a slide-valve engine. The other eccentric is fixed on the shaft and drives the exhaust valves. A variable cut-off with constant release and compression is thus obtained. Engines of this class are often called **high-speed Corliss** engines, or **four-valve** engines.

571. How would you reverse an engine when a single eccentric is used?

Most engines having valves driven by a single eccentric may be reversed by merely turning the eccentric on the shaft until its center lies on the opposite side of the shaft and makes the same angle with the crank as before. If the eccentric is fastened to the shaft with a setscrew, it can be readily turned. If the eccentric is keyed to the shaft, it will, of course, be necessary to have two keyways either in the shaft or the eccentric, one for the forward and one for the reverse motion.

572. How would you reverse shaft-governor engines?

In the case of shaft-governor engines, where the eccentric is directly attached to the governor mechanism, it is generally necessary to shift all parts of the governor to a new position in the governor case, or wheel, to which the governor is attached. For this purpose, most governor cases are provided with two sets of holes to which the different parts of the governor may be attached. To reverse the engine, the governor parts must be shifted to the opposite set of holes, after which the weights and springs must be adjusted so as to secure the required speed and degree of regulation. By carefully marking the positions of the weights and noting the tension of the springs before the governor is taken down and setting it to the same marks in the reversed position, little change in the adjustment will be required. The engine cannot be reversed if the governor case is not provided with a duplicate set of holes.

573. What methods are used for shifting the eccentric when the engine must often be reversed?

In some cases the eccentric is slotted, and attached to the shaft in such a manner that its center may be shifted across the shaft in much the same way as the eccentric of a shaft-governor engine is shifted, the principal difference being that the center of the reversing eccentric may be moved to either side of the shaft so as to run the engine either forward or backward, and it is moved by a mechanism operated by hand instead of by a governor. Another method that is sometimes used is to turn the eccentric around the shaft by some form of mechanism. One of these mechanisms consists of a sleeve carrying a short section of a screw with a large pitch. The sleeve is slid along the shaft, the eccentric is placed on this sleeve and is prevented from moving with it in the direction of the axis of the shaft; it has a thread that fits the screw section of the sleeve, and as the sleeve is moved the screw turns the eccentric to the desired position. These devices are most often used on comparatively cheap engines on which the double eccentric and the link motion are not desirable.

574. What are the double-eccentric link motions?

They are the most common devices for reversing the direction of rotation of an engine. These devices use two eccentrics, one for each direction of rotation. By means of a suitable mechanism, either of these eccentrics may be made to drive the valve at the will of the engineer. The methods that have been most used for shifting the control of the valve from one eccentric to the other are: the **hook** or **gab gear**; the **Stephenson link**; the **Gooch link**; and the **Allen link motion.** The **gab gear** is not much used now. With it, the point of cut-off cannot be varied except by the use of another eccentric and a separate cut-off valve; and it is not well adapted for use with engines that must be reversed when running at high speed. The others are so constructed that by their use the motion of the valve can be so modified as to vary the point of cut-off and to control the amount of work done in the cylinder.

575. **Explain the similarity of the motion imparted to the valve by the "link motion" to that imparted by the "shifting eccentric."**

The extreme positions of the shifting eccentric correspond with the positions of the two eccentrics of the link motion. With a shifting eccentric, the lead of the valve for different eccentric positions depends on the path followed by the center of the eccentric as it moves from its extreme to its inner position. With a link motion, as the link block approaches the mid-position from either end and cut-off becomes earlier, the construction of the link motion has the following effect on the lead: With the Gooch or **stationary** link, as it is sometimes called, the lead is constant for all positions of the block in the link. The effect on the lead of shifting the block is practically the same as for a shifting eccentric whose center is shifted along a straight line at right angles with the center line of motion. With the Allen link, there is a small variation in the lead as the block nears mid-position; and with the Stephenson link the variation is considerable. With these two, the effect on the lead is nearly the same as with a shifting eccentric whose center moves in a curved path.

576. **In a double-eccentric link motion, when are the eccentric-rods said to be (a) "open," (b) "crossed"?**

(a) With the crank on its dead center, and both eccentrics on the side of the shaft next to the link; with the link in mid-position and the eccentric rod from the upper eccentric connected to the upper end of the link, and the rod from the lower eccentric connected to the lower end of the link, the two eccentric rods will be in a horizontal position. When in this position the rods are said to be **open.** (b) When the crank, the two eccentrics and the link are in the position above described, but the eccentric rod from the upper eccentric is connected to the lower end of the link, and the eccentric rod from the lower eccentric is connected to the upper end of the link, thus causing the two rods to cross each other, the rods are said to be **crossed.**

577. Explain the effect on lead of open and crossed eccentric rods in the Stephenson link motion.

As usually made, the radius of the center line of the slot of the link in the Stephenson link motion is equal to the distance from the center of the eccentric to the center of the link block at the moment when the link is in its full forward gear position. The effect of moving the link toward its full gear position is to **decrease** the lead when open rods are used and to **increase** the lead when the crossed rods are used. Conversely, if the link is moved toward mid-gear, the lead **increases** with open rods and **decreases** with crossed rods. With crossed rods, the engine can be stopped by placing the link in mid-gear. This cannot be done with open rods, with which there is always a small port opening in mid-gear, unless the resistance to be overcome by the engine is so great that not enough steam can be admitted in mid-gear to run the engine.

578. Describe a method for setting valves with link motions.

The general method is first to put the link in full gear position for the direction in which the engine runs the greater portion of the time, and to set the valve and the eccentric for this position in the same manner as for the plain slide valve with a single eccentric. The link is then shifted to the opposite full gear position and the eccentric for that position is set. The lead, in this operation, must be equalized by shortening or lengthening the eccentric rod instead of the valve stem, as was done in the first operation. The result of the first operation of the valve and eccentric setting should be gone over and checked, so as to see that any change that has been made in the later adjustment has not had a disturbing effect on the parts first adjusted.

579. What is the single-eccentric link motion?

It is a combination of a link with the eccentric strap of a single eccentric in such a way that the direction of motion of the engine or the travel of the valve can be controlled in practically the same manner as with the double eccentric link motions.

580. Describe the radial gear and give some of its advantages and disadvantages.

The **radial gears** perform nearly the same functions as the link motions. In these gears, the motion imparted to the valve is controlled by a system of arms or links that may have their relative positions varied in such a way that the point of cut-off or the direction of rotation or both may be readily changed. The principal advantage of these gears is that for some classes of work they give a somewhat more satisfactory steam distribution than can be obtained by the use of a link motion. A serious disadvantage with some of them is that they are more complicated than the link motion and therefore more expensive and difficult to keep in good working condition. Radial gears are sometimes used in conjunction with a governor so as to form an automatic cut-off. These gears require a considerable amount of force to hold them and to move them to a new position. Therefore, they are successful only when controlled by a powerful governor, and in most cases the governor action with these gears is too slow to secure good regulation. These gears are but little used for automatic cut-offs; their principal use is on reversing adjustable cut-off engines in which a special character of steam distribution is desired.

581. Describe the poppet valve and give some of its advantages and disadvantages.

This is a type of valve, possessing a number of valuable features, that has been much used on slow and medium speed engines, but it is not applicable to engines with high rotative speeds. The **double seated poppet** valve consists of an arrangement of two disks on a single stem, so as to control two openings from different directions in such a manner that the pressure on the one disk is balanced by that on the other. If but one disk with a single opening is used, the arrangement is called a **single-seated poppet** valve. The double-seat valve can be balanced to any extent desired and can, therefore, be easily operated. It has the disadvantage that great care is required in fitting the two disks so that they will both seat perfectly. Unequal expansion of the valves, the stem, or the seat will make it difficult to keep the valves tight.

582. What methods are used for varying the point of cut-off with cam gears?

In some cases the steam cam is made with a number of steps, each of which will hold the valve open for a different length of time. By sliding the cam along the shaft, the particular step for the required point of cut-off can be made to operate the valve. Tapered cams have also been used, which, when slid along the shaft in one direction or the other, hold the valve open for longer or shorter periods.

583. Describe the gridiron valve and give some of its advantages and disadvantages.

In this type of valve, the steam-valve seat consists of a number of narrow bars, with spaces between them for the passage of steam to the port. The steam valve is a frame with a similar series of bars, having passages between them corresponding with the passages between the bars of the seat. To open the ports, the valve is moved so as to bring the passages between its bars over those between the bars of the seat. The cut-off valve is made up of a frame with a series of bars. It slides on the back of the main steam valve and cuts off the steam supply by closing the passages through the main valve. The exhaust-valve seat and valve are made up of bars similar to those of the steam seat and valve. They are called **gridiron** valves, from the resemblance they have to a gridiron. Their advantage lies in the fact that a liberal port opening can be obtained with a short range of travel. The result is that the wear of the valve and seat and the power required to operate the valve are considerably reduced. The resistance to the flow of steam through the narrow passages between the bars is considerable, and the aggregate area of the passages must, therefore, be greater than the area that would be required with a valve like a plain slide valve that provides for the passage of all the steam through a single large opening; otherwise the steam will be wiredrawn and there will be a loss of pressure in the cylinder. By the use of a sufficiently large number of bars, the aggregate area of opening can be made great enough to prevent any serious loss from wiredrawing.

584. What do you consider to be points of utmost importance for the engineer to know before trying to make adjustments of any kind to the valve gear of his engine?

It is important to know the purpose of each part and the effect that will be produced by a change in its adjustment. If, after a careful study of the machine, there is any doubt as to the purpose of any part, or if the means for making adjustments that seem to be needed cannot be discovered, it is best to apply to the makers for instructions. Since most engine builders make changes from time to time in the details of their machines, it is always best when asking for information to state clearly the size and type of engine and, if possible, to give its number and the date at which it was built and installed.

585. Why is it important to keep all joints of a valve gear carefully adjusted?

With the numerous joints existing in some gears, the aggregate effect of a small amount of slack in each will disturb the action of the valve and seriously affect the steam distribution. The pounding and rattling of loose joints is also very annoying and the rate of wear increases rapidly with increase in the amount of lost motion. If a joint is too tight, the effect will be more disastrous than if there is a moderate amount of lost motion.

586. Describe the two types of joints used in valve gears and the care they require.

The two types of joints used in valve gears are: the **solid** and the **adjustable**. The solid joint consists merely of a pin fitted in a hole or eye in the link. If a joint of this kind becomes so much worn as to give trouble, the eye may be bored out and a bushing that has been fitted to the pin forced into it. In many cases, the eye is fitted with a bushing that can be readily renewed when worn. A joint of this type requires but little attention, beyond being well oiled when in use, and it cannot be injured by ignorant and careless attempts at adjustment. With an adjustable joint, all wear and lost motion can be taken up as fast as may be desirable, and the gear can thus be kept in good working order until the joint is worn out. With these joints, it is important to note the effects of **keying up** or tightening the joints, on the length of their rods. If the change in length has an undesirable effect on the motion, it may be prevented or compensated for by the use of liners placed back of the half of the bearing that is not affected by the key or setscrew. Adjustable joints must be carefully watched to prevent the working loose of bolts, nuts, and cotters and jam nuts, setscrews, or other locking devices by which they are held in place. Attention to these details will prevent much trouble.

587. Is it possible to set the valves of an automatic cut-off engine so that cut-off will be equal for both ends of the cylinder for different loads?

On account of the disturbing effect of the angularity of the connecting-rod, it is generally impossible to so set the valves. In some gears, however, the effect on the point of cut-off of the angularity of the rod is neutralized by giving the eccentric-rod an angle with the rocker that will affect the valve motion in the same way that the angle of the connecting-rod affects the motion of the piston. In such a gear, the valve may be set for equal leads, and equal cut-off will be obtained for the whole range of cut-off.

588. When no provision is made for equalizing the cut-off how is the valve usually set?

When no provision for equalizing the cut-off is made, it is usual to set the valve for equal leads and to ingore the irregularity in cut-off.

589. In what cases would you consider it advisable to depart from this general rule?

In vertical engines, it is well to give the valve more lead for the lower port than is given for the upper one. This secures an earlier admission of steam to the lower end of the cylinder and aids in arresting the downward motion of the reciprocating parts. In many cases of fixed cut-off engines, it will be found that quiet and smooth running will be secured if the valve is set to give points of nearly equal cut-off, rather than to set for equal leads. With automatic cut-off engines that work under nearly a uniform load, or a load that varies above and below a certain value that obtains for the greater portion of the time, it will often be desirable to set the valve for equal cut-offs at the usual working load.

590. How would you determine whether the valve setting is satisfactory?

One of the most useful indications of a satisfactory setting of the valves is a quiet- and cool-running engine. If the crankpin and bearings, when carefully lined, adjusted, and oiled, persistently get hot and noisy, it is a strong indication that the setting of the valves is unsatisfactory for the conditions of load, speed, and steam pressure under which the engine runs. An indicator diagram will serve a very useful purpose as an indication of the changes that will most likely be beneficial, but it is well to remember that the particular setting of the valves that will give a fine diagram will not necessarily give the best results as far as quiet and cool running is concerned.

591. What careful attention do the flat-pressure plate valve and the piston valve demand?

Pressure-plate valves demand much careful attention to prevent leakage, which means a waste of steam. The plate, valve seat, and valve must be carefully fitted. The valve must work freely between the plate and seat without being loose enough to permit the passage of any considerable amount of steam. If the plate is adjustable by means of wedges or screws, it must be let down on the valve with great care; if it rests on edges that must be planed or scraped, the difficulties are still greater and the adjustment requires a considerable degree of skill. The only adjustments possible with piston valves are those involved in setting the packing rings so that they will fit their seats without working too tight.

592. What care should be given the valve stems and valve-gear generally regarding "packing and lubrication"?

Valve stems should be packed so as to be only just tight enough to prevent an annoying leakage of steam. This is especially true in the case of automatic cut-off engines, where any friction of the valve or valve stem has a disturbing effect on the governor action. On account of the effects of friction on the governor, as well as to prevent wear and loss of power, all parts of the gear should be thoroughly and uniformly lubricated. Efficient lubrication can be secured only when the supply of oil is uniform and steady. The best method of lubrication is that in which the parts run continually in an oil bath.

593. With a slide valve that is not adjustable along the stem, how would you mark the positions on the valve gear to assist you in making future adjustments and for determining whether or not the adjustments have been disturbed?

First, select a fixed point in some convenient place (the end of the steam-chest will generally serve well for this purpose), and mark it plainly with a center punch. Prepare a **tram** of such a length that when the point on one end rests in the center-punch mark just made, the other will reach to a convenient point on the valve stem. With the steam-chest cover off, set the valve so that it just covers one of the ports and make a center-punch mark on the valve stem at the point to which the tram reaches when its other end is in the fixed center-punch mark. Shift the valve so that it will just cover the opposite port and make a similar center-punch mark on the stem for this position. With the tram and these marks, the positions of the valve where it just covers each port can be determined and the valve can be set without the necessity of removing the steam-chest cover.

594. With some valves, the "port opening" cannot be determined by observation, owing to the fact that

the edges are hidden by the form of the valve or of its seat. In such cases, how would you locate the port opening?

If the engine can be connected with a steam supply, the points where port opening begins can be located in the following manner: Open the drain cock and disconnect the eccentric rod from the rocker or valve stem. Put the crank on either center and block it there. Turn steam into the steam chest and move the valve by hand until steam just begins to blow through the drain cocks, first at one end of the cylinder and then at the other. The valve position at which steam begins to blow from the cock at either end of the cylinder will be the position at which the port for that end begins to open. Make center-punch marks on the valve stem for these positions of the valve, to suit a tram, and a record will be had from which the valve can be set at any time.

595. **When setting valves or adjusting the gearing in any way, why should the work be carefully verified before it is finally regarded as finished?**

Because it very often happens that a change in one part will affect another that has previously been adjusted, and if the work is not carefully examined before it is left, the effect of the change will not be discovered until it is found that the engine does not work well. Therefore, after making any changes or adjustments the engine should be turned over slowly, by hand if practicable, and the motion of each part should be carefully watched in order to make sure that there are no interferences and that all parts work freely.

CONDENSERS

596. How could the efficiency of the steam engine be increased?

The only two ways of increasing the efficiency of the steam engine are, either to raise the temperature of the live steam by increasing the boiler pressure, or by superheating, or to lower the temperature of the exhaust by using a **condenser.**

597. What are the lowest back pressures obtained in "condensing" and "non-condensing" engines?

In good condensing engines, the back pressure is often as low as 2 pounds above vacuum. In non-condensing engines, the steam is exhausted into the atmosphere, and therefore the exhaust steam must have, at least, the pressure of the atmosphere. In practice, the back pressure of steam in non-condensing engines is scarcely less than 16 pounds above vacuum, and is often 17 pounds or more.

598. Give a brief explanation of the theory and object of the condenser.

The object of the condenser is to remove a large part of the back pressure on the exhaust side of the piston of a steam engine when exhausting into the atmosphere, which back pressure cannot be less than the pressure of the atmosphere. By making the engine exhaust into a condenser, the back pressure will be lowered to the pressure existing in the condenser, and, consequently, with the pressure on the steam side of the piston remaining the same as before, the net pressure on the piston will be increased by the use of the condenser. Air and vapor collect in the condenser from various sources and, if not removed, will destroy the vacuum and increase the back pressure. To get rid of this air and vapor, the condenser is fitted with an air pump, or is provided with other means by which the air and vapor are removed from the condenser, along with the condensed steam and condensing water. This operation provides and maintains a constant vacuum.

599. Explain the formation of a vacuum.

If a cubic inch of water is converted into steam at atmospheric pressure, it will occupy 1,646 cubic inches of space, and, conversely, if 1,646 cubic inches of steam at atmospheric pressure are condensed into water, they will occupy but one cubic inch of space. Therefore, if a closed vessel is filled with steam at atmospheric pressure and that steam is entirely condensed to a cubic inch of water, $^{1645}/_{1646}$ of the space will be left empty. A perfect vacuum would be the result, but a perfect vacuum is impossible in practice, because small quantities of air pass into the condenser from various sources.

600. Name some of the obstacles in the way of producing a perfect vacuum.

The feedwater of the boilers always contains a small quantity of air, which passes into the condenser with the exhaust steam and is released there when the steam is condensed. More or less air also finds its way into the condenser through leaks around the piston rod and valve stems. Another obstacle in the way of producing a perfect vacuum is due to the fact that water in a vacuum emits a certain amount of vapor, and vapor is also formed in a jet condenser or in an induction condenser by the heat in the exhaust steam, imparted to the condensing water. If the condenser were periodically filled with steam and the steam condensed after each filling, the air and vapor, if not removed, would accumulate from these various sources until the vacuum would be entirely destroyed.

601. Why does a condensing engine require more watchful attention than an engine exhausting into the atmosphere?

Because leaky steam valves and leaky pistons, which are largely responsible for the loss of steam, are not as easily detected in the condensing engine as they are in the non-condensing engine. A continuous stream of steam emitted from the exhaust pipe indicates leaky steam valves or leaky piston, or both. The only sure way to discover such leaks in a condensing engine is by means of the indicator diagram.

602. Another source of loss in a condensing engine, when independent air and circulating pumps are used, is the extravagant use of steam in the engine or engines that operate these pumps. How can such loss be prevented?

In large plants, this loss may be prevented by compounding the steam cylinders of independent air and circulating pumps, or in the case of multiple-expansion engines, by leading the exhaust steam from the engines of independent air and circulating pumps into the receiver. By so doing, the energy remaining in the exhaust steam may be converted into work in the low-pressure cylinder of the main engine. The cylinders of the air and circulating pumps should be fitted with indicator gear and cards should be taken, and the steam valves should be set with the same care that is given the main engine.

603. Define: a jet condenser; a surface condenser.

A **jet condenser** is a condenser in which the exhaust steam and the condensing water mingle, and where the steam is condensed by direct contact with the water. The **surface condenser** is a condenser in which the steam and the condensing water do not mingle. The exhaust steam is condensed by coming into contact with metallic surfaces that are kept cool by cold water constantly flowing over them.

604. Name the different types of jet condensers.

The **common jet condenser**, the **siphon condenser**, and the **induction condenser.**

605. Describe the common jet condenser.

The **common jet condenser** consists of an air-tight vessel, or **body** of the condenser, of sufficient strength to sustain the pressure of the atmosphere from without. The exhaust steam flows into this vessel from the cylinder after its available energy has been spent in driving the piston to the end of its stroke. The steam on entering the condenser is met by a jet or spray of water, forced into the condenser by the pressure of the atmosphere on the surface of the water supply outside, through the **injection pipe.** On the end of the injection pipe is a perforated enlargement, called a **rose,** which is placed in the pathway of the incoming steam. The steam and spray are thus mechanically mixed and the steam is condensed into water, which falls to the bottom of the condenser along with the injection water. From the condenser it flows through the **foot-valve** into the **air pump,** by which it is pumped into the **hotwell.** As much of the water as may be required for feeding the boilers is taken from the hotwell by the feed-pump and forced into the boilers. The remainder of the water in the hotwell flows through the **discharge pipe** into the sewer or elsewhere. The form of a **common jet condenser** is immaterial, but it is important that it be placed so that the water cannot be drawn from it into the cylinder in case of flooding.

606. What is the danger of flooding the condenser?

Should the condenser become flooded there is danger that the water may be drawn into the cylinder and that it may blow out the cylinder head or break the piston. Besides, when the condenser is full of water, there is no room for the exhaust steam to enter and a vacuum cannot be formed until the air pump clears the condenser of its superfluous water.

607. What causes a condenser to get hot?

If the condenser is deprived of injection water, the incoming steam cannot be condensed, and it will accumulate in the condenser until the pressure is equal to or greater than the pressure of the atmosphere outside. This condition will cause the condenser to get hot.

608. When a common jet condenser gets hot, what is the remedy?

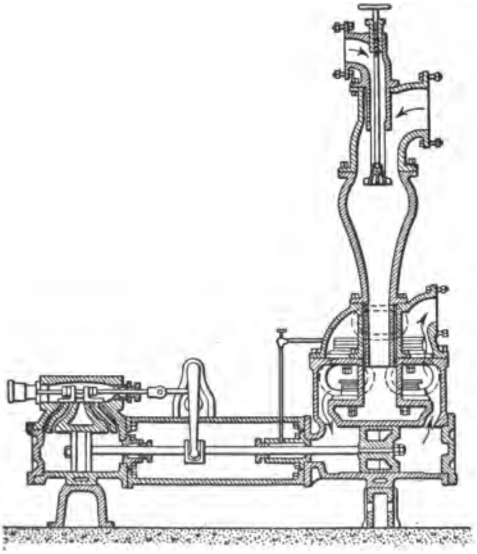
Common jet condensers are usually fitted with a water pipe connected with one of the auxiliary pumps, by which cold water is forced into the condenser and a vacuum is produced thereby. This pipe is provided with a valve, which should be kept closed when not in actual use, to exclude any air that might leak into the condenser through the auxiliary pump. If no such pipe is provided, it will be necessary to deluge the outside of the condenser with cold water from a hose or buckets.

609. If the injection water is impure, what is to be done?

All the water in the hotwell should be allowed to run to waste and pure feedwater supplied from another source.

610. In what way do the later designs of jet condensers differ from the common jet condenser?

The later designs now generally used, occupy less space, and the air pump is usually a double-acting, horizontal pump operated by an independent engine, but the principles involved are practically the same.



A Jet Condenser.

611. Describe the Worthington independent jet condenser.

Cold water enters the condenser, passes down a spray pipe, and is broken into a fine spray by a cone. The exhaust steam at the same time enters the condenser, and is rapidly condensed by mingling with the spray of cold water. The velocity of the entering steam carries the whole mixture of steam, water and air through the cone into the air-pump cylinder, with a high velocity, and is forced by the pump through the discharge pipe.

612. With what velocity does the exhaust steam of an engine enter a good vacuum?

About 1,900 feet per second.

613. With what velocity does the water enter the condensing chamber?

About 47 feet per second.

614. What are some of the advantages of the independent jet condenser over the common jet condenser?

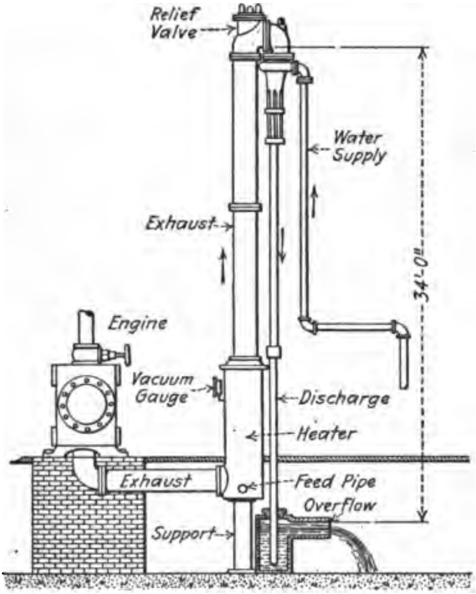
In the common jet condenser, the injection water and the condensed steam fall to the bottom of the condensing chamber before entering the air pump, thus losing the momentum acquired by water rushing into a vacuum. In the independent jet condenser this force is utilized to assist the pump by increasing the velocity of the falling water. In the independent jet condenser the load on the pump is more steady and regular, and the danger of working back of the water into the engine cylinder is less than with the common jet condenser.

615. Describe the siphon condenser.

In the siphon condenser the vacuum is generated and maintained by a column of water flowing downward through a vertical pipe of not less than 34 feet in length, with its lower end immersed in the water of the hotwell. As long as the proper amount of water continues to flow into the upper end of this pipe and a corresponding amount flows out at the lower end, the air and vapor in the condenser will be carried out by the fall of the water and a vacuum will be formed and maintained therein. The area of the pipe is contracted into a neck, or throat. This increases the velocity of flow of the water, which reduces the possibility of the condenser's becoming flooded and the water working back into the engine cylinder. It improves the action of the condenser generally. It is important that the stream of injection water should be steady and continuous, and that there should be no leaks in the exhaust pipe or condenser. With the siphon condenser, no air pump is required to remove the air, uncondensed vapor, and water, but a circulating pump or a head of water is needed to supply the injection water when the lift is more than 20 feet. When the lift is 20 feet or less, the water will be siphoned over as soon as a vacuum is formed, and a circulating pump will not be necessary. With this type of condenser, a tank is sometimes placed about 15 feet below the condenser from which the injection water is forced into the condenser by the atmospheric pressure upon the surface of the water in the tank. This tank is supplied with water by an ordinary tank pump or from the street main. Like other condensers, the siphon condenser is provided with a valve that opens into the atmosphere to relieve it of the accumulation of steam, air or vapor. The surplus water in the hotwell flows into the sewer.

616. Describe the induction condenser.

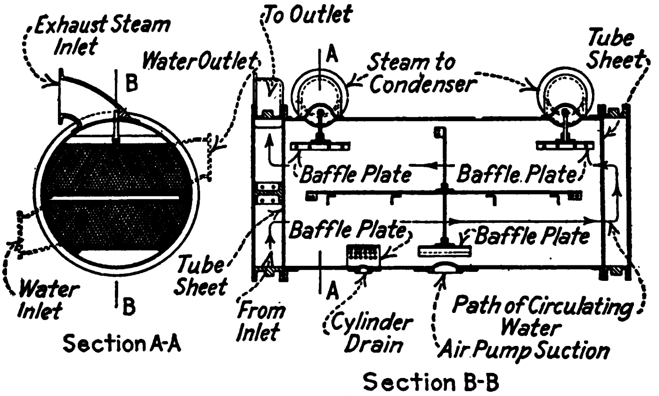
The operation of the induction condenser is based on the same principle as that of the steam injector, used for boiler feeding. The exhaust steam, after passing through a balanced horizontal check-valve, enters a water chamber. It then passes into a condensing chamber where it is met by a supplementary stream of injection water and is condensed, forming a partial vacuum. The vacuum induces the injection water to be siphoned into the condenser from the supply reservoir through the injection pipe, where it meets the exhaust steam and condenses it. The injection water and the water of condensation mix and with the air and vapor are carried down a discharge pipe into the hotwell, the surplus water flowing into the sewer. These condensers are made so as to enable the operator to control the volume of water admitted to the condensing chamber so as to provide for the varying quantities of steam to be condensed. Like all other condensers, they are always provided with a valve that opens into the atmosphere to relieve them of the accumulation of air, steam, or vapor. This valve closes automatically when the condenser contains a vacuum and opens automatically when the vacuum is destroyed. This valve may be locked open at any time when it becomes necessary or desirable to cut the condensing apparatus out of service and to run the engine non-condensing. This valve is called a **snifting valve, snifter,** or **relief valve.** A check-valve is provided to prevent the water in the condenser from being siphoned back into the steam cylinder.



An Induction Condenser.

617. Describe the surface condenser.

The body of the surface condenser is an air-tight, cylindrical or rectangular vessel. When the exhaust steam enters the condenser it strikes a perforated scattering plate, which distributes the steam evenly over a nest of tubes, and also protects the upper tubes from the direct effect of the exhaust steam. When the steam comes into contact with the cold surface of the tubes, through which cold injection water is forced by a circulating pump, it is condensed into water and falls over another nest of tubes where it is further cooled before it falls to the bottom of the condensing chamber, whence it drains to the air pump. To relieve the condenser of any excess steam, air or vapor, it is provided with an automatic relief valve, sometimes called the **snifting valve,** which opens automatically into the atmosphere. In the event of the air pump's becoming inoperative for any cause, the engine can be run non-condensing by exhausting through this valve into the atmosphere.



A Surface Condenser.

618. In what way does the surface condenser differ from the jet condenser?

(See Answer 603.)

619. What are the advantages of the surface condenser?

The water of condensation and the circulating, or injection water, are kept entirely apart in the surface condenser. This is an advantage of great value, particularly when the injection water is so impure as to be unfit for feedwater.

620. Part of the steam that is generated in the boiler is lost in various ways, and the exhaust steam from the engine is not enough to keep up the supply of feedwater. When a surface condenser is used, how is this deficiency made up?

A by-pass pipe is sometimes fitted around one of the tube-sheets in such a manner as to allow a communication to be opened up between the steam and water sides of the condenser. The deficiency can be made up by drawing the necessary amount of water from the circulating side of the condenser by opening the cock or valve provided for that purpose.

621. Is it advisable to make up the deficiency in feedwater from the injection supply? Why?

No. Though it is sometimes necessary it is objectionable, particularly when the injection water is so impure as to be unfit for feedwater. The object of the surface condenser is to supply the boilers with pure feedwater—the water of condensation. If the injection water be used to any extent, the water in the boilers will become impure and the object of the surface condenser will be destroyed. It is better to make up the loss of water with purified or distilled water, if possible, and keep impurities out of the boilers entirely rather than to use patent compounds, chemicals, or kerosene oil, or to allow the impurities to form scale and mud to the detriment of the boilers, incurring loss of fuel and time and the expense of cleaning them.

622. What is the effect of grease on the tubes of a surface condenser?

Grease being a non-conductor of heat, the efficiency of the condenser is seriously impaired when the tubes become thickly coated with it. The grease must be removed to restore the usefulness of the condenser.

623. How is grease, carried over from the engine cylinder, cleaned from a surface condenser?

When **animal** or **vegetable** oils only were used for lubricating the piston this was comparatively an easy matter. The condenser was fitted with a cock, variously called an **impermeator, alkali cock,** or **soda cock,** by which caustic soda, or caustic potash, was injected into the steam side of the condenser. The alkali coming into contact with the grease converted it into soap. The soap would be dissolved and washed out through the drain cock. To assist this operation a small live steam pipe entered the condenser near the bottom through which steam was let into the steam side of the condenser after it was filled with water, to such a height as to cover the top row of tubes, and the alkali then injected. This **boiling-out** of the condenser was a very efficient way to get rid of the grease. But since

mineral oils are now used for cylinder lubrication almost entirely, the **boiling-out** process is no longer practicable, because alkalies have no effect upon mineral oils. The grease deposited upon the condenser tubes from mineral oils must be removed by hand. To do this, the tubes are removed. In drawing the tubes, the greater part of the grease is scraped off the tubes by the tube-sheet. To scrape the grease off the tube-sheets, a man may go inside the condenser through manholes provided for the purpose. This grease is very sticky, and is very difficult to remove from tubes and tube-sheets, and also from the skin and clothing of the man. It can be softened by the use of kerosene oil, or gasoline. If gasoline is used, no naked light should be used near the condenser, because the vapor given off is highly inflammable.

624. How can grease be kept out of the condenser?

By the use of an efficient **grease extractor** in the exhaust pipe. This apparatus is largely used in well-equipped steam plants, and contributes greatly toward keeping condensers and boilers free from grease.

625. Describe the tubes and tube-sheets used in surface condensers.

The latest practice is to make them of a composition consisting of copper, 70 per cent.; zinc, 29 per cent.; tin, 1 per cent. They are usually 5/8 inch outside diameter, No. 18 B. W. G. in thickness, and are spaced 15/16 inch between centers. They are carefully tinned within and without, and when they are 6 feet or over in length, they are supported by one or more supporting plates. The tube-sheet should be 1 inch thick and made of the same composition as the tubes, with smoothly finished holes for the tubes and proper means provided for packing them.

626. Describe the method of packing condenser tubes.

The packing used for this purpose is either cotton tape, cotton lamp wicking, or a rubber ring. Screw glands, that screw into the tube-sheet and down on the packing, are provided. These screw glands are counter-bored so as to form a shoulder, to prevent the tubes from **crawling.** The glands are slotted to admit a tool for screwing up.

627. Why is it necessary to give condenser tubes end play?

Condenser tubes are subjected to extremes of expansion and contraction due to the great changes in temperature which take place. If they were rigidly fixed in both tube-sheets, they would become warped, bent, and distorted, and would soon be destroyed. A space between the end of the tube and the shoulder of the screw gland is provided to give the tube end play.

628. What is the cause of leaks in a surface condenser?

The extreme expansion and contraction of condenser tubes often causes them to split. The tube packing will also give out in time, causing leakage.

629. How may a serious leak be detected?

Serious leakage may make itself known by a noticeable increase in the quantity of water discharged by the air pump.

630. What is the objection to leaks in surface condensers?

Serious leaks, if permitted to continue, will destroy the object of the surface condenser by admitting the impure injection water to the steam side.

631. How is a surface condenser tested for water leaks? How are the leaks remedied?

The test for leaks is made by removing the condenser bonnets and filling the steam side of the condenser with water. If water flows from any of the tubes, it proves that those tubes are split, and they should be replaced with new tubes. If the leaky tubes cannot be replaced just then, they may be plugged up at both ends temporarily with dry white-pine plugs. Defective tube packing should be replaced.

632. How may air leaks in a surface condenser be detected? How stopped?

They can generally be detected by the whistling sound the air makes while being drawn into the condenser, or by holding a lighted candle along the joints. Where there is a leak, the flame will be drawn inwardly. Air leaks are also revealed by a poor vacuum, all other conditions being right. Air leaks in a condenser can be stopped by setting up on the nuts of the bonnet or gland. If this does not stop the leak, it may be plastered over with red-lead putty containing a small proportion of litharge.

633. What precautions are generally taken against the deteriorating effects of galvanic action in surface condensers?

The condenser tubes are tinned both outside and inside to prevent the acidulated water from coming into contact with the copper in the tubes. **Plates of zinc** are suspended in the air-pump channel ways and in the hotwell or feed tank. The galvanic current attacks the zinc more readily than iron or steel and its destructive energy is used up in destroying the zinc. The zinc plates are enclosed in wire baskets to prevent the larger particles of zinc that become detached from the plates from obstructing the bottom blow. The metal straps by which the zinc plates are suspended should be filed bright where in contact with the zinc and the metal from which they are suspended. After the straps are bolted in place, the outside of the joints should be made water-tight by covering them with paint or cement.

634. What is the cause of galvanic action in surface condensers?

One of the impurities found in water is sulphuric acid. This acid, in connection with the copper in the condenser tubes and the iron of the condenser casing, feedpipes, and boilers, constitutes a galvanic battery, which sets up a galvanic current, causing rapid corrosion that is especially injurious to the boilers.

635. What is a cooling tower?

It is a device for the purpose of cooling the discharge water from a condenser and so using it over again as injection water.

636. Describe the construction and principle of the cooling tower.

The cooling tower generally consists of a tower-like structure, usually at least 30 feet high. The warm water is pumped to the top of this tower and then allowed to fall to the bottom against a current of air which is driven upward often by a fan blower. In falling downward the water is broken into a spray by coming into contact with obstructions placed in its path for the purpose of presenting the greatest possible area of evaporating surface to be acted upon by the air. The cooling towers in use differ somewhat in construction and material, but are all governed by the same principle. The principle is that the evaporation of a part of the water being cooled extracts the heat from the remaining part. The amount of water evaporated must be restored from some original source of supply.

637. Name the fittings required on a condenser to make it complete.

A vacuum gauge; thermometers for the injection water, feedwater and outlet circulating water; a reverse air valve for the circulating pump; sometimes an alkali cock; a by-pass pipe; drain cocks; manholes and handholes; a glass water gauge, and a vacuum breaker.

638. What is the object of the vacuum gauge, and where should it be located?

The object of the vacuum gauge is to indicate the pressure, below that of the atmosphere in the condenser. It should be located where the engineer can consult it conveniently at any time.

639. What is the object of the thermometers and how should they be connected?

The object of the thermometers is to determine the temperatures of circulating water and condensed steam. These thermometers should be permanently connected to the condenser by means of small pipes, through which streams of the various waters should be kept circulating around the bulbs of their respective thermometers so that the temperatures of the waters may be noted at a glance.

640. How are the condenser temperatures regulated?

The condenser temperatures are regulated by passing more or less circulating water through the condenser tubes, as required. This is done by means of the injection valve, or by the varying speed of the circulating pump, if it is independent of the main engine.

641. What is the cause of slamming of the valves in a circulating pump, and how may the trouble be remedied?

In the winter the injection water may be very cold and not enough of it required for condensation to fill the barrel of the circulating pump. This will cause **slamming** of the valves. If the circulating pump is independent of the main engine, the trouble may be remedied by slowing down the pump; but if the pump is operated by the main engine, as is common in marine practice, a reverse air valve is fitted to the barrel of the circulating pump, which will allow a certain amount of air to enter the pump at each stroke and relieve the slamming. This valve is regulated or permanently closed by a screw stem and hand wheel. Another method of accomplishing the same result is to provide a communication, by a pipe or channel way, between the discharge and the receiving chambers of the circulating pump, fitted with a valve, which, when opened, will permit a part of the circulating water to return to the receiving chamber of the pump instead of passing through the condenser tubes.

642. Describe the alkali cock, with which marine surface condensers are usually provided, and its object.

The **alkali cock** is an ordinary plug cock screwed into the top of the condenser over and near the center of the upper nest of tubes. It has a funnel-shaped top through which an alkaline solution may be poured into the condenser for the purpose of dissolving the grease that collects upon the tubes from the exhaust steam.

643. Describe the by-pass and its object in connection with a surface condenser.

A **by-pass** pipe containing a cock or valve is fitted around one of the tube-sheets of a surface condenser, whereby any deficiency of feedwater from the condensed steam may be supplied from the circulating water, if there is no other source of supply.

644. How many drain cocks should a condenser be provided with?

A condenser should be provided with a sufficient number of drain cocks, so located as to completely drain all the water out of it.

645. What is the object of manholes and handholes in condensers?

To afford access to the interior of the condenser for examination, cleaning and repairs. They should be located wherever necessary and practicable.

646. What is the object of the glass water gauge on the hotwell or feed tank?

It is to indicate the water level within the hotwell or tank and thus inform the engineer as to the sufficiency or insufficiency of the feedwater supply.

647. Describe the vacuum breaker and its object.

A **vacuum breaker** is a necessity in connection with a jet condenser. It will automatically break the vacuum in case of a sudden breakdown of the air pump, and will thus prevent the filling up of the condenser and then the engine cylinder with water. A vacuum breaker is usually constructed in the form of a float-operated valve opening from the condenser to the atmosphere. It is so placed that when the water in the condenser exceeds a certain height the valve will open and admit air, thus destroying the vacuum and preventing a further inrush of injection water.

648. How many pounds of condensing water are required to condense a pound of steam?

The number of pounds of condensing water required to condense a pound of steam depends on the vacuum and the final temperature of the condensed steam and the initial and final temperatures of the condensing water.

649. How can the weight of condensing water per pound of steam be found?

To find the weight of condensing water per pound of steam, from the total heat of a pound of exhaust steam subtract the difference between the final temperature of the condensed steam and 32; divide the remainder by the difference between the temperatures of the entering and departing condensing water. This rule is not exact but the error is on the safe side.

650. What may cause an imperfect or low vacuum in a condenser?

A low vacuum may be caused by an insufficient supply of condensing water; the air pump may be out of order, or there may be air leaks.

651. How can the cause of a low vacuum in a condenser be ascertained?

If a log of the performance of the engine is kept, the cause may be ascertained easily. In this log the temperature of the hotwell, the temperature of discharged circulating water, and the initial temperature of the entering condensing water, are entered every hour or oftener. If the vacuum in a surface condenser is found imperfect, the temperatures of the hotwell and of the discharged condensing water should be ascertained. If these temperatures are higher than have been noted down in the log book for a more perfect vacuum, the indication is that not enough condensing water is supplied. If an increased supply of condensing water fails to improve the vacuum, the indications are that there is an air leak somewhere about the condenser or engine. If no air leak is found, some of the air-pump valves may be broken or in poor condition. In a jet.condenser the temperature of the hotwell and that of the outlet condensing water are always the same, since the exhaust steam and condensing water mingle. Therefore, if the hotwell temperature is the same as in the case of a more perfect vacuum, the trouble is either an air leak or a partially disabled air pump. If the hotwell temperature rises, the trouble is due to an insufficient supply of injection water.

652. How much vacuum can be obtained in a condenser?

Owing to mechanical imperfections of the condensing apparatus, the best vacuum that may be obtained in a condenser will rarely be within 2 inches of the maximum possible vacuum. (The maximum vacuum obtainable can never be more, in inches of mercury, than the height of the column of the barometer, at the same time and place.)

COMPOUND ENGINES

653. What are some of the mechanical advantages of the compound engine over the simple expansive engine of equal power?

The advantages of the compound engine over the simple expansive engine are that the pressure on the bearings is more even throughout the stroke and not so high at the beginning of the stroke; and, by dividing the whole range of expansion into two or more parts and performing the work in separate cylinders, an economy in the use of steam is effected.

654. Why cannot a high ratio of expension be economically used in a single cylinder?

Because the gain due to the high ratio of expansion is lost entirely or even overbalanced by the loss due to the initial condensation of the entering high-pressure steam, which is occasioned by the cooling of the cylinder walls during exhaust.

655. Why does the division of the temperature range between several cylinders tend to reduce cylinder condensation?

In most cases, if not in all, the time during which the entering hot steam is in contact with the cylinder walls is so short that the incoming steam cannot heat them to its own temperature. Likewise, the time during which the cylinder walls are in contact with the exhaust steam is usually so short that they do not cool entirely down to its final temperature. Consequently, the fluctuation of temperature of the cylinder walls is less than the temperature range of the incoming and exhaust steam. The rate at which heat passes from a hot body to a cold body depends on the difference in temperature between the two bodies. When the temperature difference is great, the rate of heat transmission is much larger than it would be if the temperature difference were small. In other words, the rate at which transfer of heat takes place increases faster than the temperature difference. It follows from this principle, when the difference in temperature between that of the incoming steam and that of the cylinder walls is small, that less heat, in proportion to the temperature difference, will be given up to reheat the cylinder walls than would be the case for a larger temperature difference. Similarly, if the temperature of the exhaust steam is but little below that of the cylinder walls, less heat in proportion to the temperature difference will be lost by the cylinder walls. Therefore, by expanding steam successively in several cylinders, we not only decrease the temperature range in each cylinder, but also greatly decrease the fluctuation in temperature of the cylinder walls of each. Then, as the rate of heat transmission is proportionally much smaller for a small fluctuation of temperature, it follows that the sum of the condensation losses in the several cylinders will be smaller than the condensation loss occurring in a single cylinder having the same temperature range between the initial and final temperature. Another probable cause of reduction of cylinder condensation by compounding is that the steam condensed in the high-pressure cylinder and reevaporated during the exhaust period enters the low-pressure cylinder as **steam;** hence, the heat given up in the high-pressure cylinder by the entering steam in heating the cylinder walls is not a total loss, as would be the case if exhaust took place into the atmosphere or into a condenser, instead of exhausting into a second cylinder.

656. State some of the advantages of the compound and triple-expansion engines over the simple-expansion engine with regard to the working parts and flywheels.

The pressures, and consequently the strains, in a triple-expansion or a compound engine are more evenly distributed throughout the stroke than they are in a simple engine, and the turning moment on the shaft is also more nearly uniform. Therefore, lighter working parts can be used with the same margin of safety, and lighter flywheels, to give the same regularity of speed. These lighter weights and more even strains mean less friction in the engine, which results in a saving of coal.

657. What is a tandem compound engine?

An engine that has two cylinders in line with each other in which both pistons are carried on the same piston rod, and the exhaust from the high-pressure cylinder passes through an exhaust passage into the steam chest of the low-pressure cylinder.

658. What is a cross-compound engine?

An engine in which the high-pressure cylinder and the low-pressure cylinder are placed parallel to and alongside of each other. Both cylinders are connected to a common crank-shaft which carries the flywheel between the bearings and has cranks at each end. These cranks are placed at right angles to each other, so that when one crank is on a dead center, the other is midway between the centers. In consequence of this there is a much more uniform turning moment on the crankshaft than in a tandem compound engine, and the engine will run much steadier.

659. In a cross-compound engine how is the exhaust from the high-pressure cylinder passed into the low-pressure cylinder?

The exhaust from the high-pressure cylinder passes through the high-pressure exhaust pipe into a receiver and thence through the receiver steam pipe into the low-pressure steam chest.

660. What are the two general types into which compound engines may be divided?

They are the **Woolf compound type** and the **receiver compound type.**

661. Describe the Woolf compound type engine.

In the Woolf compound type the pistons of each cylinder commence and complete the stroke at the same time, and, consequently, the high-pressure cylinder can exhaust directly into the low-pressure cylinder. In this type of engine, either both pistons operate directly upon one crank, as in a tandem compound engine, or they operate upon two or more cranks on the same shaft, which are either in line or 180° apart. The absence of a receiver is the distinguishing feature of the Woolf compound engine.

662. In what cases is a tandem-compound engine fitted with a receiver?

As far as the steam distribution is concerned, a tandem-compound engine does not need a receiver, but some of them, especially in very large sizes, are fitted with reheating receivers, where an additional amount of heat is supplied to the high-pressure exhaust in order to reduce the cylinder condensation in the low-pressure cylinder.

663. Describe the receiver compound engine.

In this type of compound engines the high-pressure cylinders exhaust into a separate vessel, chiefly in order that the cranks may be placed at any desired angle other than 0° (in line with each other) or 180° apart. This cannot be done without the use of a receiver. The receiver, however, need not be a separate vessel, but may be in the form of a very large exhaust pipe from the high-pressure to the low-pressure cylinder, or may be formed by an exceptionally large low-pressure steam chest.

664. Why is a receiver needed when the cranks of a compound engine are at any other angle than 0° or 180° with each other?

In a cross-compound engine, for instance, with cranks 90° apart and cutting off at ½ stroke in both cylinders, the low-pressure piston will be just past its mid-stroke position and the low-pressure steam port will be closed when the high-pressure piston will just have commenced its stroke. But while the high-pressure piston is taking live steam on one side, it is exhausting on the other side, and, the low-pressure steam port being closed, the high-pressure exhaust steam will be compressed in the low-pressure steam chest and the passage leading to it. This compression means a waste of work, which is saved by the use of a receiver.

665. Define the expressions compound, triple-expansion, quadruple-expansion, quintuple-expansion engines.

These expressions refer to the number of different stages in which the steam is expanded, and should not be taken to mean that the steam is expanded to twice, three times, etc., its original volume, or that the engine has two, three, four or more cylinders.

666. What is a three-cylinder, three-crank compound engine?

It is a compound engine built with three cylinders and three cranks, there being one high-pressure cylinder and two low-pressure cylinders. In this engine one half of the exhaust from the high-pressure cylinder passes to each low-pressure cylinder. It is distinctly a **compound** engine.

667. Define (a) simple-expansion; (b) multiple-expansion engines.

(a) All single-cylinder engines in which the expansion of steam takes place in one stage; (b) all engines in which the expansion of steam takes place in more than one stage.

668. How is the size of a multiple-expansion engine generally stated?

It is customary to give the sizes of the cylinders in inches, commencing with the smallest cylinder, and to write the stroke in inches last.

669. What are the intermediate-pressure cylinders?

In the triple-expansion engine there is at least one cylinder, and in the quadruple-expansion engine there are at least two cylinders between the high-pressure and low-pressure cylinders, through which the steam must pass. These cylinders are called the **intermediate-pressure** cylinders.

670. How are the cylinders in compound and multiple-expansion engines designated?

H. P. = **high-pressure** cylinder; I. P. = **intermediate-pressure** cylinder; 1 I. P. = **first intermediate-pressure** cylinder; 2 I. P. = **second intermediate-pressure** cylinder; L. P. = **low-pressure** cylinder.

671. What is a steeple-compound engine?

Tandem compound engines may be vertical or horizontal; when vertical they are often called **steeple-compound.**

672. What is meant by the term drop when applied to the pressure in a receiver?

When the volume of steam drawn out from the receiver is greater than the volume of steam in the high-pressure cylinder at the moment release begins in that cylinder, the exhaust steam rushing into the receiver must expand to the volume drawn from the receiver. In expanding, the pressure of the exhaust steam drops, so that the pressure in the receiver and the back pressure on the high-pressure piston are less than the pressure at the time of release. This difference in pressure at the time of release and in the receiver is termed **drop.**

673. What effect has the drop in a receiver on the steam entering it?

When steam is allowed to expand without doing any work the steam becomes dried or even superheated to an extent depending on the **drop.** The effect of this is partially or entirely to evaporate any water in the steam, thus tending to reduce the initial condensation in the low-pressure cylinder. The expanding of steam without doing any work is termed **free expansion.**

674. How may the most economical receiver pressure for a given engine be found?

The most economical receiver pressure may be found by experiment, regulating the pressure and noting the effect upon the steam consumption.

675. How is the receiver pressure regulated?

The receiver pressure is regulated by making the cut-off earlier or later in the high-pressure cylinder and leaving the low pressure cut-off as before.

676. How does a change in high-pressure cut-off affect the receiver pressure?

By making the cut-off later a larger volume of steam will enter the receiver and the receiver pressure will be higher. Making the cut-off earlier means a lower pressure at release and a lower receiver pressure.

677. What effect will a change in receiver pressure have on the amount of work done in the cylinders?

If the receiver-pressure is higher the initial pressure in the low-pressure cylinder will also be higher, and, the low-pressure cut-off being the same, the mean effective pressure will be greater. The mean effective pressure being greater the power of the engine is increased. A lower receiver pressure will decrease the mean effective pressure in the two cylinders, and the power of the engine will also be decreased.

678. How may the drop in a receiver be regulated?

By means of the low-pressure cut-off. If the cut-off in the low-pressure cylinder is made later, a larger volume of steam will be drawn from the receiver, and the receiver pressure will be less and the **drop** more. If the low-pressure cut-off be made earlier, there will be less steam drawn from the receiver, and the receiver pressure will be higher and the **drop** less.

679. Why is it best to govern a compound engine by changing both the high-pressure and low-pressure cut-off?

A change in the high-pressure cut-off will change the power of the engine, while a change in the low-pressure cut-off will change the distribution of work between the two cylinders. When the load is increased and the governor makes the high-pressure cut-off occur later, a larger share of the total work will be done in the low-pressure cylinder. If the load drops and the governor hastens cut-off in the high-pressure cylinder, the larger share of the work will be done in the high-pressure cylinder, and at very early cut-offs the low-pressure cylinder may actually be a drag on the engine. It is therefore best to have the governor operate both the high-pressure and the low-pressure cut-offs. In that case the governor operates the high-pressure cut-off in order to change the power of the engine and the low-pressure cut-off in order to equalize the amount of work done in the two cylinders. When the load is increased, the governor makes cut-off later in both cylinders; when the load is reduced, the governor makes cut-off earlier in both cylinders.

680. Name the fittings necessary in connection with a receiver, and their object.

Receivers should always be fitted with **compound gauges** registering from zero to the maximum pressure in one direction and from zero to 30 inches of vacuum in the other direction. Receivers should also be fitted with large **pop safety valves,** so that in case the low-pressure cut-off should be set too early, or if the releasing gear should fail to open the low-pressure admission valves, the steam would be released. Otherwise, the high-pressure cylinder would pump the receiver full of steam and cause it to explode.

681. How would you set the valves of multiple-expansion engines?

In setting the valves of horizontal multiple expansion engines, a rather large amount of lead should be given in the low-pressure cylinder. The lead for a 48 inch, low-pressure, condensing cylinder may be from ¼ to 5⁄16 inch, and if the back-pressure is very low the lead may be somewhat larger. The valves of each cylinder of a compound and triple-expansion engine must be set in relation to the crank on which that cylinder is doing its work. For vertical engines it is customary to give a little more lead on the bottom than on the top, for the reason that the force required to accelerate the reciprocating parts is greater on the up stroke than on the down stroke, due to the weight of the reciprocating parts. In many of the valve gears now in use, the action of the valve is so quick at the instant of opening that many engineers measure the lead not from the amount that the valve is open when the engine is on the center, but from the position of the crank when the valve begins to open. The practice with some engineers is to have the valve begin to open when the crank is still 15° from the dead center. This angle, however, may be regarded as a limit. Perhaps 7° to 10° would be the average.

682. How is it best to distribute the work between the cylinders of a multiple-expansion engine?

In practice it is probably the best plan, when the design of the engine permits it, to distribute the work between the cylinders so as to obtain the smallest possible steam consumption compatible with steady and satisfactory running.

683. How can this object be attained?

This object can only be attained by repeated trials, changing the receiver pressures in order to change the work done in each cylinder and noting the steam consumption after each change.

684. Is it always possible to change the distribution of work in the two cylinders of a compound engine? Why?

No. In many compound engines, especially in the high-speed type, the distribution of work in the two cylinders has been determined upon by the builder and cannot be changed by any means at the command of the engineer. The valves of both cylinders are generally under the control of the governor, and the angle of advance is a fixed quantity which cannot readily be changed. All that the engineer can do is to keep the valves centrally set and the engine in first class running condition.

685. Define steam-jacketed cylinder.

When the cylinder of an engine is surrounded with a casing and the space between the cylinder and casing is filled with live steam during running, the cylinder is said to be **steam-jacketed.**

686. What is the object of the steam jacket?

To prevent condensation from taking place in the cylinder.

687. Describe briefly the application and care of the steam jacket.

In slow-speed engines, say up to 150 revolutions per minute, using saturated steam, a properly applied and properly cared for steam jacket will produce a distinct gain in economy, while one that is improperly applied or cared for will prove a loss and sometimes a very serious one. If possible it is always best to use steam in the jacket at a higher temperature than that of the steam which enters the cylinder. In a compound engine the jacket may be applied to the high-pressure cylinder and the receiver, and in a triple-expansion engine to the first and second cylinders and to both receivers, but in neither case need it be applied to the low-pressure cylinder.

688. Describe how the steam jacket prevents condensation taking place in the cylinder, and the gain effected by its use.

In an unjacketed cylinder a portion of the entering steam is condensed in heating up the cylinder head, piston and cylinder to the temperature of the steam, as it is hotter than the metal with which it comes in contact. As the piston moves forward, uncovering fresh surfaces of the cylinder, the condensation continues until the point of cut-off is reached. The steam then commences to expand and correspondingly lowers in pressure and temperature, and unless the steam is cut off very early in the stroke, no further condensation takes place after the cut-off has taken place for the reason that, as soon as the temperature of the steam falls through expansion, the head, piston and walls of the cylinder already heated begin to give up their heat to the steam and thus prevent further condensation taking place. As the expansion is carried still farther and the temperature of the steam correspondingly lowered, a portion of the water previously condensed is reevaporated into steam by the heat given up by the piston, cylinder, and head, raising the terminal pressure in the cylinder. When the piston arrives at the end of the stroke, the exhaust valve opens and the pressure and temperature of the steam lower immediately, the remainder of the water previously condensed then being reevaporated by the heat extracted from the cylinder walls, piston, and head and passed out with the exhaust steam. The exhaust steam is much colder than the metal, and during the whole of the return stroke is absorbing heat from the cylinder walls, piston, and head, lowering their temperature, which has to be raised again by the steam entering for the next forward stroke. The action of the heat above described takes place very quickly and affects the metal of the cylinder and head to a slight depth only, as there is not time for it to penetrate very deeply; but it affects it at each stroke of the engine, and a small loss each stroke amounts to a very large one during a day's run. The action that takes place in a steam-jacketed cylinder is quite different In case of a high-pressure cylinder of a compound or triple-expansion engine the jacket contains steam at the same temperature as the steam entering the cylinder. The jackets are so arranged that neither air nor water can collect and interfere with their usefulness. At the beginning of the stroke the cylinder and head will be at the same temperature as the entering steam, and none of the entering steam will be condensed by them, as in the case of an unjacketed cylinder. The piston itself will be in the same condition as before, and a portion of the steam will be condensed and reevaporated by it. After the admission of steam ceases and the temperature of the steam inside the cylinder becomes less through expansion, heat is transferred from the cylinder walls to this steam, reevaporating the small amount of water condensed by the piston. The walls, in turn, absorb heat from the steam in the jacket, condensing some steam in the jacket, but maintaining the cylinder at nearly an even temperature. When the exhaust valve opens and the pressure and temperature of the steam in the cylinder become lower, there is no water to reevaporate; but as the steam inside the cylinder is then much cooler than the walls of the cylinder, it absorbs heat from them during the whole of the return stroke, which heat, in turn, is absorbed from the steam in the jacket, and this heat is practically wasted. The quantity wasted is small, because the steam is now pretty dry. The actual gain effected by the use of a steam jacket on a cylinder is the difference between the saving due to the prevention of condensation in the cylinder at the beginning of the stroke and the loss by heating the exhaust steam during the return stroke. This gain may in many cases be very slight.

689. What is a reheater and what is its object?

The **reheater** is a modification of the receiver commonly used in multiple-expansion engines and consists essentially of a receiver containing coils or nests of small pipes, through which high-pressure steam circulates and which are so arranged that the working steam must circulate around them thoroughly and become **reheated.**

690. What is the gain effected by the use of a reheater?

The advocates of the reheater claim that a gain of 10 per cent. can be effected by its use under favorable conditions. This, however, depends entirely on circumstances, and a reheater, instead of causing a gain, may cause a positive loss. Furthermore, it can seldom or never be predicted beforehand whether a reheater will cause a gain or a loss; but it can always be determined afterward whether the action of the reheater is profitable.

691. If, in using a reheater, the temperature of the exhaust is found to be greater than that corresponding to its pressure, what does this indicate?

If the temperature of the low-pressure exhaust steam is greater than that corresponding to its pressure, the reheater is wasting heat, and the reheater should be abandoned, or the supply of live steam to its coil cut down.

692. Describe the construction of some form of reheater.

The reheater commonly used consists of a cast-iron or wrought-iron shell, having at one end a tube plate secured between the shell and the cover. A large number of small wrought-iron boiler tubes are expanded into this tube plate. These boiler tubes are expanded at the other end into a tube plate, which is bolted to the head. The head and tube plate form a vessel that is independent of the outer shell of the receiver, so that the tubes are perfectly free to expand or contract. One end of the reheater is closed by a cover through which a steam pipe and an air drain pipe pass. Stuffing boxes are used to make a steam-tight joint where these pipes pass through the head. An automatic air valve is generally attached to the air pipe, through which the air is discharged when starting up and which closes as soon as the steam reaches it. The other pipe serves as a drain and is led to a trap. The shell is also provided with a drain, leading to a trap. In proportioning the reheating surface, 40 square feet of surface are generally allowed for every cubic foot of steam exhausted into the reheater by the high-pressure cylinder per stroke. The exhaust from the high-pressure cylinder enters the reheater and is compelled by baffle plates to circulate around the coils, through which high-pressure steam is circulated, and then passes through an opening into the low-pressure steam chest. For very large engines reheaters are often constructed like tubular boilers, the tubes being expanded into rigid tube-sheets riveted to the shell. The working steam, then, generally passes through the tubes, while the steam used for reheating circulates outside of them. With such a reheater it is a good plan to take the live steam for the reheater from a connection placed between the throttle and the engine. If this is done, steam will be admitted to both sides of the reheater as soon as the engine is started, and its expansion will be more uniform, which renders it less liable to leakage around the tube ends.

693. Should a reheating receiver be used when the engine uses superheated steam? Why?

No. For the reason that the steam entering the receiver usually contains enough superheat to prevent initial condensation, and the use of a reheating receiver under these conditions will result in a direct waste of heat.

694. To what is the ratio of expansion of a multiple-expansion engine equal?

It is equal to the ratio between the volume of steam in the low-pressure cylinder at low-pressure-release, and the volume of steam admitted to the high-pressure cylinder. The ratio of expansion is independent of the low-pressure cut-off or the volume of the receiver.

695. How may the ratio of expansion of a multiple-expansion engine be found?

To find the total ratio of expansion, divide the volume of the low-pressure cylinder up to the point of release, including clearance, by the volume of the high-pressure cylinder up to the point of cut-off, including clearance. Or multiply the ratio of expansion of the high-pressure cylinder by the volume of the low-pressure cylinder up to the point of release and divide by the total volume swept through by the high-pressure piston, clearance included. The ratio of expansion calculated by this rule is known as the **ratio of expansion by volume.** The ratio of expansion of a multiple-expansion engine is sometimes given as the ratio between the absolute pressure at the point of cut-off in the high-pressure cylinder and the absolute pressure in the low-pressure cylinder at the point of release. The

ratio of expansion by pressure is, for the same engine, almost always greater than the ratio of **expansion by volume,** owing to drop in the receiver. The absolute pressures are taken by measurement from indicator diagrams.

696. How is the indicated horsepower of compound engines calculated?

The indicated horsepower of a compound or triple-expansion engine is calculated from the indicator diagrams in exactly the same manner as with any simple engine, considering each cylinder as a simple engine and adding the horsepowers of the engines together.

697. In taking the indicator cards from a compound engine, what precaution must be observed?

The precaution must be observed of taking the cards simultaneously from all cylinders, especially when the engine runs under a variable load, since otherwise an entirely wrong distribution of power may be shown, and there may also be a great variation between the indicated horsepower really developed and that calculated from the diagrams taken at different times.

698. Can the horsepower of a multiple-expansion engine be estimated accurately?

No. It cannot be estimated with any degree of accuracy, on account of the fact that the mean effective pressure cannot be estimated very closely, and for this reason it is better to take the mean effective pressure from diagrams whenever this is feasible. The horsepower of a multiple-expansion engine is sometimes estimated by estimating the horsepower of a simple-expansive engine having the same dimensions as the low-pressure cylinder, the same piston speed, the same initial pressure, and the same total ratio of expansion.

699. How should the probable mean effective pressure of a simple-expansive engine be estimated?

To estimate the probable mean effective pressure of a simple-expansive engine, it is necessary to assume an initial and terminal pressure in order to determine the probable ratio of expansion **by pressures.** With a steam pipe of ample size and the throttle wide open, the **initial pressure** in the high-pressure cylinder will probably average 5 pounds per square inch below the boiler pressure. The **terminal pressure,** i.e., the pressure at the point of release in the low-pressure cylinder, may be assumed to average 9 pounds absolute in condensing engines and 19 to 22 pounds absolute in non-condensing engines. Then, the **total ratio of expansion,** by pressure, will be the absolute initial pressure divided by the absolute terminal pressure. This determination of the total ratio of expansion is based on assumptions that may differ considerably from the conditions actually existing. Hence the determination of the mean effective pressure is only approximate at best, and the horsepower of the engine cannot be estimated with any great degree of accuracy. The **absolute back-pressure** may be estimated at 17 pounds for non-condensing engines and 3 pounds for condensing engises. These values are average values and will vary somewhat from the true values that may actually obtain with a given engine. This introduces another source of error in the estimation of mean effective pressure. The mean effective pressure having been estimated, the horsepower is calculated in the same way as the horsepower of any simple engine is calculated.

ENGINE MANAGEMENT

700. What is the first duty of an engineer in taking charge of a plant?

In taking charge of a plant, the first duty of the engineer is to make a thorough inspection of all parts of it in order to become familiar with every detail of the machinery and appurtenances. He should notice particularly whether any parts of the engines, pumps, etc., are disconnected or removed. If any parts have been removed he should examine them carefully. If the cylinder heads are off, he should examine and try with a wrench the follower bolts and piston-rod nuts. He should carefully examine the cylinder walls, and if they are cut, grooved, or pitted, he should make a note of the fact for future reference and comparison. The clearance between cylinder head and piston should be measured and marked on the guides with a center punch in order to find out and preserve a record of the space there is to spare for taking up the wear on the connecting-rod journals. The cylinders should be wiped out with oily waste and a coating of cylinder oil should be applied to the wearing surfaces before closing up the cylinders. If the valve-chest covers are off, the condition of the valves and seats should be noted. The lead of the valves should be examined, by turning the engines over by hand, having first poured a little oil into the journals. The valve gear should be watched during the operation of turning the engine, to see if there is any derangement. All obstructions to the free turning of the engine should be removed. If the pump-valve bonnets are off, the valves and valve chambers should be examined. If the valves are of flat, hard rubber, and any of them are much worn on their lower faces, they should be turned over; if they are curled from standing dry for some time, they should be faced off. If the condenser bonnets are off, the engineer should examine the interior of the condenser. If a surface condenser, he should fill the steam side of the condenser with water and look for leaky tubes. All leaky tubes and tube packings should be replaced with new ones. Before replacing any of the covers, bonnets, or cylinder heads, the engineer should make sure that no tools, waste, or other matter are left inside. All gaskets should be examined, and if found torn or worn out, they should be replaced with new ones. A thin coating of graphite should be applied to all gaskets before they are put in place. If the connecting rod is disconnected at the crankpin he should examine the condition of the crankpin and brasses. If they are cut or rough, they should be scraped down with a scraper and finished off with a smooth file. The crankpin brasses should not be set up too tight on the pin. It is better to leave them a little slack and take them up after the engine has been running for a while. He should examine the piston-rod and valve-stem stuffing boxes and add some packing or repack them, if necessary. He should examine the drain cocks and cylinder relief valves to see that they are not stopped up. He should examine the feed pump most carefully, and see that the packing is in good condition and that the petcock is not stopped up. He should trace up the pipes, commencing with the suction pipe at the pump. He should follow up the suction pipe to the source of the feedwater supply, and examine every foot of it. He should satisfy himself that there is nothing the matter with the water supply. Starting again at the pump, he should follow up the delivery pipe, tracing it through all its windings to the point where it enters the boiler. The check-valve should be taken out. If found in good condition, it should be wiped off with oily waste and replaced. If found in poor condition it should be repaired or replaced with a new one. He should try the globe valve in the feedpipe and see that it works freely. If any of the globe valves are found to work stiffly, the stems and threads should be oiled, and repacked if necessary. He should trace all auxiliary steam and exhaust piping to and from the various auxiliary engines and pumps. If the exhaust pipes of the auxiliary system lead to a condenser, he should locate the valves for changing the auxiliary machinery from non-condensing to condensing and vice-versa. If the main engines are condensing, he should examine the air pump and circulating pump and their valves, and trace up all steam and water pipes leading to and from them. He should locate all cocks and valves in the piping and ascertain what every one of them is for, particularly all those connected with the feedwater supply system. If the plant is supplied with such appliances and apparatus as separator, filter, economizer, evaporator, superheater, etc., they should all be included in the inspection, and should receive the same attention and care as the other parts of the machinery. If the water of condensation is saved for use in boilers by leading the various drain pipes into a manifold, from which a single drain pipe conveys the water to a steam trap, and thence another pipe carries it to the hotwell or feed tank, the various drain pipes should be traced up and examined. All leaky or broken joints should be repaired at once. If badly rusted pipes are found, he should note whether they are exposed to unusual dampness or to dripping water. If such is the case, a coat of thick red-lead paint or paraffin varnish should be applied. All other iron or steel piping under the floor should be treated in the same manner. In fact, if during the inspection anything is found that is out of order, he should have it repaired at once.

701. Describe how the steam pipes and engine should be warmed before starting up.

A few minutes before starting, the stop-valves should be raised just off the seats to allow a little steam to flow into the steam pipes. The drain cock on the steam pipe above the throttle should be open. When the steam pipe is thoroughly warmed up, the drain cock should be closed and the throttle opened just enough to let a little steam flow into the valve chest and cylinder, or the by-pass around the throttle should be used, if one is fitted. If the engine is non-condensing, the cylinder, valve chest and exhaust pipe drain cocks should be opened. If the cylinders are jacketed, the steam should be turned into the jackets and the drain cocks opened. Give the engine a few minutes to warm up. Further operations in warming up the cylinder will depend somewhat on the type of engine and valve gear. But in general, all cylinders should be warmed up slowly, as sudden heating is very liable to crack the casting by unequal expansion.

702. **What way is there to warm up the steam pipes and engine without the use of steam?**

One way to warm up the pipes and engine is to open the stop-valves and throttle valve as soon as the fires are started in the boilers, permitting the heated air from the boilers to circulate through the engine. This will warm it up gradually and prevent the accumulation of a large quantity of water of condensation in the steam pipes and cylinder. When steam shows at the drain pipes of the engine, the stop-valves and throttle may be closed temporarily, but not hard down to their seats. When this method of warming up is adopted, the gauge cocks should not be opened while steam is being raised.

703. **Why should stop-valves and throttle never be opened suddenly?**

If stop-valves or throttle are opened suddenly, the large volume of steam that enters the cold steam pipe or cylinder will be condensed and a partial vacuum will be formed. This will be followed by another rush of steam with the same result, and so on until a mass of water will collect, which will rush through the steam pipe and strike the first bend in the pipe with great force, sometimes breaking it and causing a disaster. This is called **a water hammer.**

704. **What precaution should be taken regarding the throttle valve during the operation of warming up the engine?**

The throttle valve should be lifted just off its seat before steam is turned into the main steam pipe, because the unequal expansion of the valve casing may cause the valve to stick fast and give much trouble. Even if a by-pass pipe is fitted around the throttle, it would be better not to depend on it.

705. **Having all steam pipes drained and the engine warmed up, what is the last thing an engineer should do before taking his place at the throttle?**

He should start the oil and grease cups feeding, or make sure that it was done by the oiler. The oil should be fed liberally at first, and adjusted after the engine has been running a few minutes and the journals are well lubricated.

706. When a plant has been shut down after a run, what attention should the machinery receive?

Both the bright work and the painted parts of the machinery should be wiped off before the oil has had time to set. Rusty spots on the bright work should be scoured off with emery cloth. Drip pans should be emptied and cleaned out, and the engine room generally should be cleaned up and the dirt gathered together and removed.

707. When flour emery or emery cloth is used for cleaning bright work on an engine, what care should be exercised?

Great care should be exercised not to let any of the grit get into the journals and bearings. All oil holes in the small joints and journals that are not fitted with oil cups should be plugged up after the engine is stopped and kept closed until the engine is ready to be started again. Brass or composition should be polished with bath brick, as this is much better than emery cloth for this purpose.

708. Describe the course of procedure for starting a slide-valve non-condensing engine, after the stop valves are open and the pipes and cylinder warmed up.

As both steam ports cannot be open to steam at the same time, the engine should be turned by hand so that both steam ports are opened in turn and steam admitted to both ends of the cylinder. After turning, the engine should be stopped on its upper or lower half center. After the engineer has satisfied himself that the condensation of steam has ceased, and that all water has been blown out from the pipes, valve chest and cylinder, the engine is started by opening the throttle quickly in order to jump the crank over the first center, after which the momentum of the flywheel will carry it over the other centers. The engine should be run slowly at first, gradually increasing the revolutions to the normal speed. The drain cocks should then be closed, if dry steam is blowing through them; if water is being delivered, the drain cocks should be left open for a while. The bearings should then be examined to see whether they are running cool. If cool, the oil feed should be decreased gradually until there is just enough to supply the demand without waste. If the bearings are found to be blood warm, they should be watched, because they are liable to get hot.

709. **If a cracking noise is heard in the cylinder after the engine has been running for a while, what is the cause and how can it be remedied?**

The cracking noise is due to water in the cylinder, and the cylinder drain cocks should be opened promptly. If this is caused by priming at the boiler it may be checked by closing the main stop-valve just enough to wiredraw the steam a little.

710. **Explain the procedure in shutting down a slide-valve non-condensing engine.**

To shut down an engine of this type it is necessary only to shut off the supply of steam by closing the throttle. With large size engines, care should be taken not to let the engine stop on its dead centers. After the engine is stopped, the oil feed should be shut off and the main stop-valve closed so as to be seated but not jammed down on the seat. The **drain cocks** on the steam pipe and engine may or may not be opened, according to circumstances.

711. **What is the advantage, if any, in leaving the cylinder drain cocks closed after the engine has been shut down?**

With the drain cocks closed, the steam will condense inside and cool the engine down gradually, which lessens the danger of cracking the cylinder casting by unequal contraction. All water of condensation should be drained from the engine before steam is again admitted to it.

712. **Describe the course of procedure when starting a slide-valve condensing engine.**

If the engine is fitted with a surface condenser, the air pump and circulating pump should be put in operation and a vacuum formed in the condenser, before the main engine is started. This will assist the engine in starting promptly, and in cases where the engine is worked to bell signals this is a most important consideration. Before starting the air and circulating pumps, the injection valve should be opened to admit the condensing water into the circulating pump, and the delivery valve should also be opened at this time. The pumps should be warmed up in the same manner as the main engine, before starting. After the main engine has been running for a few minutes to equalize temperatures, the speed of the air and circulating pumps and the admission of injection water should be regulated so as to maintain about 26 inches of vacuum in a surface condenser and a feedwater temperature of about 115° F. As a rule, there should be about 2 pounds of back pressure on the exhaust side of the piston, which is equal to 4 inches on the vacuum gauge and to a feedwater temperature of about 115° F.; therefore, the reading of the vacuum gauge should be about 4 inches below the reading of the barometer to get the best results from the engine. If an ordinary jet condenser is used, only an air pump is required, the circulating water being forced into the condenser by the atmospheric pressure. If the air pump is operated by the main engine, a vacuum will not be formed in the condenser until after the engine is started, and at least one upward stroke of the air pump is made. In this case the injection valve must be opened at the same moment the engine is started, otherwise the condenser will get hot and a mixture of air and steam will accumulate in it and prevent the injection water from entering. If the air pump is operated by an independent steam cylinder, the air pump should be started before the main engine is started and a vacuum thereby formed in the condenser beforehand, and it should be stopped after the main engine is stopped.

713. **Why should the vacuum in a surface condenser be maintained at about 26 inches, when the barometer stands at 30 inches?**

Because a higher vacuum than 26 inches will result in a loss of heat from cold feedwater, and it will also cause a high-speed engine to thump while passing the centers through insufficient compression or cushion for the piston, while a lower vacuum than 26 inches will cause a loss by too much back pressure.

714. What is a vacuum engine?

When the air pump and the circulating pump are operated by a separate and independent cylinder, the apparatus as a whole, including the condenser, is called the **vacuum engine.**

715. Describe the procedure when stopping a slide-valve condensing engine.

The operation of stopping a slide-valve surface condensing engine is the same as that of stopping a non-condensing engine of the same type, with the addition that after the main engine is stopped the vacuum engine is also stopped, after which the injection valve and the discharge valve should be closed and the drain cocks opened. With a jet condenser the operation of stopping the engine is the same, with the exception that the injection valve should be closed at the same moment that the engine is stopped.

716. Describe the procedure when starting a simple Corliss engine.

After all the preliminaries, such as warming up and draining the water from the engine, starting the oil feed, etc., have been attended to, the starting bar is slipped into its socket in the wristplate and the throttle is opened. To determine in which direction the starting bar should be first moved to start the engine ahead note the position of the crank to learn the direction in which the piston is to move. This will indicate which steam valve to open first and the direction in which the starting bar should be moved. The starting bar is then vibrated back and forth by hand, and as soon as the cylinder takes steam the engine will start. After working the starting bar until the engine has made several revolutions and the flywheel has acquired sufficient momentum to carry the crank over the first center, let the hook of the eccentric rod drop upon the pin on the wristplate. As soon as the hook engages with the pin, unship the starting bar and place it in its socket in the floor. If the engine is of the condensing type, the vacuum engine should be started in the same way as with the simple slide-valve condensing engine. The oil feed, etc., should then receive the engineer's attention, as usual.

717. Describe the procedure for stopping a simple Corliss engine.

A Corliss engine is stopped by closing the throttle and unhooking the eccentric rod from the pin on the wristplate, by means of the unhooking gear provided for the purpose. As soon as the eccentric rod is unhooked from the pin, ship the starting bar into its socket in the wristplate and work the engine by hand to any point in the revolution of the crank at which it is desired to stop the engine. The course of procedure then is the same as with the simple slide-valve engine. After stopping a Corliss condensing engine, cylinders should be drained, stop-valves closed, etc., the same as in the case of the simple slide-valve condensing engine. Let the engine come to a stop very slowly.

718. Describe the operations of starting a compound engine.

Before starting a compound engine, the high-pressure cylinder is warmed up in the same manner as a simple engine. The method of getting the steam into the low-pressure cylinder will depend on circumstances. If the cylinders are provided with pass-over valves, it will only be necessary to open them to admit steam into the receiver and from there into the low-pressure cylinder. If the cylinders are not provided with pass-over valves, the steam is worked into the receiver and low-pressure cylinder by operating the links back and forth, if the engine has a link motion. When no pass-over is fitted, steam can be worked into the low-pressure cylinder by working the high-pressure valves back and forth by hand. Some compound engines are fitted with starting valves, which greatly facilitate the operation of warming up and starting. Usually a compound engine will start upon opening the throttle. If no way exists for getting steam into the low-pressure cylinder while the high-pressure crank is on a dead center, it must be pulled or jacked off.

719. It sometimes happens that compound engines will refuse to start. State some of the causes, and the remedy in each case.

(1) The high-pressure crank may be on its center. If the low-pressure engine will not pull it off, it must be jacked off. (2) There may be too high or too low a steam pressure in the receiver. If the pressure of steam in the receiver is too high, causing too much back pressure in the high-pressure cylinder, the excess of pressure must be blown off through the receiver safety valve; if the pressure in the receiver is too low to start the low-pressure piston, more steam must be admitted into the receiver. (3) The engine may be stiff from standing idle a long time, and the oil in the journals may have become gummy. The pistons may be rusted fast in the cylinders, or the cylinders may not have been wiped out after the last run and a coating of carbonized oil and rust may have collected on their walls and caused the pistons to stick fast. In this case all wearing surfaces must be well oiled and the engine jacked over at least one entire revolution. (4) If the engine is fitted with independent adjustable cut-offs, the cut-offs may happen to be set too early. If the cut-offs are run up, they should be run down, full open. (5) There may be water in the cylinders. It should be blown out through the cylinder relief or drain valves. (6) There may be some obstruction to the free turning of the engine. The obstruction should be located and removed.

720. In starting a compound condensing engine, (a) is the use of an independent vacuum engine advantageous? (b) Why?

(a) Yes. (b) If the air and circulating pumps are attached to and operated by the main engine, a vacuum cannot be generated in the condenser until after the main engine has been started. In this case, there is no vacuum to help start the engine, and it is tardy or will refuse to start. With an independent vacuum engine, a vacuum is generated in the condenser beforehand, and the pressure in the receiver acting on the low-pressure piston causes the engine to start very promptly, even though the high-pressure crank may be on its center. With compound condensing engines of high power that are required to run in either direction in answer to signals, the independent vacuum engine is indispensable.

721. If the engine is fitted with adjustable cut-offs, how should they be manipulated?

They should be so manipulated that the engine will run smoothly and at the lowest steam consumption. The only way of finding the proper points of cut-off is by experiment, setting the cut-offs where judgment and experience dictate and noting the effect upon smoothness of running and the steam consumption.

722. Briefly describe the procedure for stopping a compound slide-valve engine.

Compound slide-valve engines, whether condensing or non-condensing, are stopped by closing the throttle, and, if reversing engines, by throwing the valve-gear into mid-position. The usual practice of draining the engine, steam chest, and receiver, closing stop-valves, stopping the oil feed, etc., should be followed the same as with other engines.

723. Explain the procedure when stopping and starting a compound slide-valve engine, if it is intended to run in both directions in answer to signals.

After stopping the engine on signal, the engineer should immediately open the throttle very slightly in order to keep the engine warm, and stand by for the next signal. If the engine is fitted with an independent or adjustable cut-off gear, it should be thrown off, for the reason that the engine may have stopped in a position in which the cut-off valves in their early cut-off position would permit little or no steam to enter the cylinders, in which case the engine will not start promptly, or may not start at all. While waiting for the signal, the cylinder drain valves should be operated and left open long enough to blow out any water that may be in the cylinders. When the signal to start the engine is received, it is only necessary to throw the valve gear into the go-ahead or backing position, as the signal requires, and to operate the throttle according to the necessities of the case, as the position of the throttle will depend on the load on the engine at the time. Handling the throttle must be learned by experience on the spot.

724. Explain the operation of starting and stopping a Corliss compound engine.

The operation of starting and stopping a Corliss compound engine is similar to that of starting and stopping a Corliss simple engine. The high-pressure valve gear, only, is worked by hand in starting, the low-pressure eccentric hook having been hooked on previously. The low-pressure valve gear is worked by hand only while warming up the low-pressure cylinder. So far as the treatments of the air pump, circulating pump, condenser, oil feed, etc., are concerned, the course of procedure is the same as for operating a simple compound engine.

725. What is the difference in the manner of starting, stopping and reversing triple- and quadruple-expansion engines, and compound engines?

The management of triple- and quadruple-expansion engines is the same as that practiced with the compound engine, with the exception that there are more moving parts, more journals, more hand gears, and more machinery, in general, to look after, requiring greater activity and alertness on the part of the engineer to care for it.

726. Explain the purpose of lining an engine.

Lining an engine is for the purpose of locating the different parts so as to have no undue strains exerted on any one of the parts and to reduce the friction of the moving parts to a minimum.

727. In lining an engine, can absolute accuracy be attained?

No. If it could be attained it could not be maintained. However, great care should be exercised in lining an engine, as its future smooth running and efficiency will depend very largely on the accuracy with which this operation is performed.

728. In lining an engine, what requirements must be fulfilled?

1. The center line of the shaft must be at right

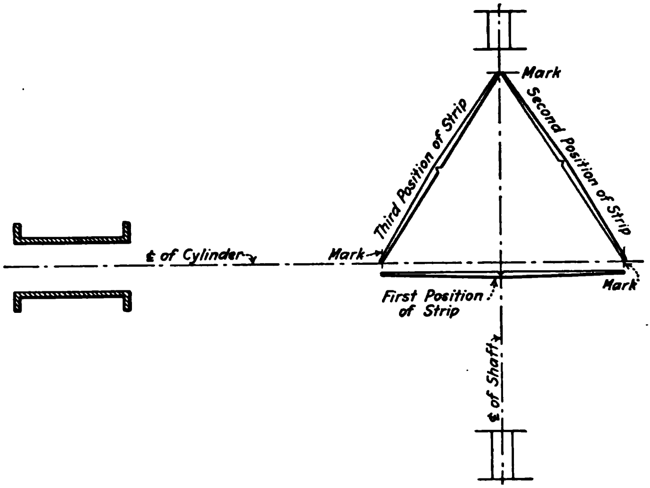
angles to the center line of the cylinder. 2. The wearing surfaces of the guides must be parallel to the center line of the cylinder. When two guides are used, they must be parallel to each other, and usually equidistant from the center line of the cylinder. 3. The center line of the wristpin must be at right angles to the center line of the cylinder and must lie in the same plane. 4. The center line of the crankpin must be parallel to the center line of the shaft. 5. The center lines of the cylinder and of the shaft must both lie in the same plane. 6. The center lines of the bore of the brasses at both ends of the connecting-rod must be parallel to one another and must be at right angles to the center line of the connecting-rod. 7. The center line of the piston rod must coincide with the center line of the cylinder. In addition to the above, it is generally necessary that the crank-shaft be level.

729. What is the first step in lining an engine, and how may this be done?

The first step in lining an engine, after all the moving parts have been removed and the cylinder heads taken off, is to stretch a line coincident with the center line of the cylinder. It may be done in the following manner. A strip of board or other material is secured to the head end of the cylinder by means of the stud bolts and nuts. A hole about 1 inch in diameter is bored through the strip approximately in line with the center of the cylinder. Some form of standard should be erected at the crank end of the bedplate, and pierced in the same way as the strip of board secured to the head end of the cylinder. A very fine braided cord or piece of thin annealed copper wire should be stretched very tightly through the holes. In order to permit ready adjustment, each end of the line should be fastened to the middle of a piece of round iron, or passed through a hole in the center of a piece of stout sheet tin or other metal, and a knot made at each end of the line to prevent slipping through the holes. If the line used is a fine wire, two holes may be punched in each piece of sheet metal and the end of the wire passed through one of the holes, brought back through the other, and the end stopped off around the main part of the line. The pieces of metal should be cut about 2 inches square, and the diagonally opposite corners turned up at right angles to form handles by which they may be adjusted. The line should be set central to the bore of the cylinder at the head end by calipering from the inside of the cylinder counterbore to the line. This may be done with a pair of inside calipers, but in most cases it is better to use a light pine stick. The stick should be about one inch shorter than the radius of the cylinder counterbore and tapered at each end, with a thin 1-inch wire nail driven into each end, making the total length of the stick, including the nails, the exact radius of the counterbore. If the calipers or stick will just touch the line, no matter from which point of the circumference of the counterbore the measurement is taken, the head-end part of the line will be central to the bore of the cylinder. If the measurements do not agree, the line must be shifted in the direction shown by the variation until it coincides with the center line of the cylinder. It is considered good practice to make four measurements 90° apart. The crank-end part of the line may be trued up in a similar manner by moving the line near where it is attached to the standard. After the crank end of the line is trued up, the head end of the line may be a shade out of the center, and therefore its alignment should be tried again. After adjusting the head end of the line, the crank end should be tried again and adjusted. These adjustments should be continued, first at one end of the cylinder and then at the other, until no further adjustment is possible. If the crank-end head is cast solid with the cylinder, the line must be trued up from the bore of the piston-rod stuffing-box.

730. Describe the various steps in lining an engine, after the center line of the cylinder is stretched.

After completing the adjustment of the center line of the cylinder, another line is stretched through the center of the main bearings to coincide with and represent the center line of the shaft. It must be at right angles to the center line of the cylinder and must be level. To accomplish this, it is necessary to erect two standards, to which to fasten the line. The top brasses and caps of the main-shaft bearings should be in place just as they would be if the shaft itself were in place The alignment of this line with reference to the bearings can be tested by calipers. To facilitate the adjusting of this line, blocks of wood may be fitted into the bore of the bearings and the line passed through the holes in the center of these blocks. This line may be approximately squared with the center line of the cylinder by a carpenter's square pressed gently against the two lines. If the square shows that the lines are not at right angles to each other, the center line of the shaft should be shifted until they are, always keeping



Method for Squaring the Center Line of the Shaft.

in mind the fact that the line must coincide with the center line of the bearing. In lining engines of the larger sizes, the carpenter's square is not accurate enough, its legs being too short in proportion to the length of the lines. A different method must then be used. Procure a slender strip of wood, the length to be according to the extent of the space to work in. Taper the strip to a point at each end, divide the strip into two exactly equal parts and mark it plainly in the middle. Now hold the strip gently along the center line of the cylinder with the mark in the middle at the center line of the shaft. Mark the center line of the cylinder at each end of the strip; then put one end of the strip at one of the marks just made on the center line of the cylinder and the other end of the strip against the center line of the shaft and mark the place where the end of the strip touches it; repeat this operation on the other side of the center line of the cylinder, and if the end of the strip touches the center line of the shaft at exactly the same spot that it did before, the two lines are at right angles; if it does not touch it at the same spot, the center line of the shaft must be shifted in the right direction and the whole operation must be repeated until the end of the strip does touch the center line of the shaft at the same point at both trials. In shifting the center line of the shaft, care must be taken that its position through the center line of the bearing is maintained. To mark the lines, tie a piece of bright-colored thread around the lines at the desired points. The colored threads can be easily seen and shifted along the lines at will. To prevent any displacement of the line while measuring, place blocks of wood against it at the points marked, in order to steady it; but care must be used not to deflect the lines; when the blocks are properly placed, they may be temporarily secured in position. The next step is to level the center line of the shaft. This line may be tested by means of a spirit level. Another method is to drop a plumb-line from overhead, touching the line. If the line is level, it must be at right angles to the plumb-line. This condition can be tested in the same manner as was used for determining the position of the center line of the shaft with reference to the center line of the cylinder. In leveling the center line of the shaft, it should not be allowed to touch the center line of the cylinder; it should pass just over it or just under it. After leveling the center line of the shaft, it is well to verify the relative alignment of both lines. In lining up a new engine or an old engine with new shaft-bearing brasses it is best to have the center line of the shaft lay about $\frac{1}{32}$ inch above the center line of the cylinder, so that as soon as the brasses and journals have worn down to their bearings, the center line of the shaft will be very nearly on a level with the center line of the cylinder. In many engines the outboard bearing is movable to a certain extent and may be adjusted with respect to the inboard bearing. Having proved the correct alignment of the center line of the cylinder and the center line of the shaft, the outboard bearing may be shifted until the center line of the shaft coincides with its center line, and secured in position permanently. The next step is to test the alignment of the guides. After the center line of the shaft is leveled, a spirit level may be used to ascertain if they are in the proper plane with this line. Their adjustment relative to the center line of the cylinder may be tested in one direction by placing a straightedge successively at each end of the guides and squarely across them. If the measurements from the lower edge of the straightedge down to the center line of the cylinder agree at both ends of the guides, they are in line vertically. If not, the same ends of both guides must either be raised or lowered, remembering that raising one end of the guide is equivalent to lowering the other end. By measuring from the inside edges of the guides to the center line of the cylinder, it may be ascertained whether the guides are parallel to each other and parallel to the center line of the cylinder. A spirit level may be placed squarely across the guides at both ends, to ascertain whether the guides are in a horizontal plane. In lining the guides of a Corliss engine, a special device is often used for this purpose. The next step is **bedding the shaft.** After having removed the center line of the shaft, the crank-shaft, crank, and flywheel are put in place, care being taken not to disturb the center line of the cylinder. The bearings should now be adjusted so that the shaft will turn easily in them, and the journals of the shaft should be wiped out and given a coat of red or black marking material. The shaft should then be placed in its bearings, with the lower halves of the brasses in position, and rocked back and forth a few times. The shaft is then lifted out of the bearings and the high spots scraped off with a half-round scraper. This should be repeated until the shaft shows a good bearing in both the main pillow-block and the outboard bearing. The upper halves of the brasses should now be put in place and fitted in like manner. The shaft is then lifted from its bearings, the eccentrics and governor-driving device placed in position, and the shaft returned to its place. To test the alignment of the shaft, or in other words, to make sure that the shaft is exactly at right angles with the center line of the cylinder, the crankpin is brought up to the center line of the cylinder and a piece of wood is fitted parallel to the crankpin. A mark is made on this piece of wood to coincide with the center line of the cylinder. The shaft is then turned until the crankpin is brought under the line at the other end of its travel. If the mark on the wood again coincides with the center line of the cylinder, the shaft and the line are at right angles to each other. To test the leveling of the shaft, a fine plumb-line should be suspended vertically at the crank end of the shaft and the crankpin brought into contact with it at the upper half-center so that the end of the crankpin just touches the line. The crankpin should then be brought into contact with the line at the lower half-center. If the end of the crankpin again touches the line, the shaft is horizontal. Lining the crosshead is the next step. After removing the center line of the cylinder, the piston, piston-rod, and crosshead are put in place. If the design of the piston is such as to make it necessary to center it in the cylinder, this adjustment should be made first of all. The next step is to ascertain whether the center line of the piston coincides with the center line of the cylinder. The upper surface of the guides, having been properly aligned, is parallel to the center line of the cylinder; the piston having been previously centered, the center line of the piston rod coicides with the center line of the cylinder; therefore, the piston rod should be parallel with the upper surface of the guides. This may be tested by placing the piston at the forward end of its stroke; then laying a straightedge across the guides at each end, and measuring downward from the lower edge of the straightedge to the piston rod. If the two measurements agree, the piston rod is in line; if not, the crosshead shoes must be adjusted until the piston rod is in its proper position. The next step is to test the accuracy of the crankpin, which may be done as follows: Connect the connecting-rod to the crankpin and key up the brasses snugly to the pin; then put the crank on or near one of its dead centers, and press slightly against the wristpin end of the connecting-rod, in order to take up any lost motion in the crankpin brasses. The crosshead should be pushed back toward the cylinder, so as to be out of the way. Then measure from the wristpin end of the connecting-rod to the edge of the guide, and make a note of it. Put the crank on or near the other dead center and again measure as before. If the two measurements agree, it proves that the center line of the crankpin is parallel with the center line of the shaft in the horizontal plane. To test the conditions in the vertical plane, put the crank first on the upper half center and then on the lower half center, taking measurements as before. If these measurements agree, the crankpin is properly lined. If there is a small error, it may sometimes be remedied by filing and scraping the crankpin, but if the error is serious, it may require machine work. Testing the bore of crankpin and wristpin is the next step. To ascertain if the bore of the crankpin brasses is at right angles with the center line of the connecting-rod, put the crank, with the connecting-rod attached to the crank but disconnected from the crosshead, on one of the dead centers. Measure the distance from the inner side of one of the guides to the crosshead end of the connecting-rod, and make a note of it; then take the rod off the pin and turn the rod half way around and replace it on the pin, and measure as before. If the two measurements agree, the brasses are correctly bored. To make this test still more satisfactory, the operation may be repeated for several different positions of the crank. To test the wristpin end of the rod, the rod is disconnected from the crankpin and the measurements are taken from the face of the crank or from the collar of the crankpin to the crankpin end of the connecting-rod. If the bore of the brasses is not at right angles with the center line of the connecting-rod, the brasses must be fitted to the crankpin and wristpin by chipping, filing, and scraping. The next step is to test the alignment of the wristpin. To do this, key the connecting-rod snugly to the wristpin, having it disconnected from the crankpin. Place the crank on or near one of its dead centers and push the crosshead forward until the end of the connecting-rod just rests on the crankpin. If the center line of the rod is the same distance from both collars of the crankpin the wristpin is in the correct position in one direction. Now put the crank on one of its half centers and measure as before. If the result is the same as before, the wristpin is in its correct position. The next and last step is testing the alignment of the connecting-rod brasses with reference to each other. It is very necessary that the center lines of the crankpin brasses and the wristpin brasses lie in the same plane, because, otherwise, the brasses when keyed tightly to one pin will not fit the other pin—they will bear on one side only. To make this test, put a thin coating of Prussian blue or red-lead paint on the crankpin, connect up the rod and adjust it rather snugly to the wristpin, and a little less snugly to the crankpin. Then turn the crank through one revolution, and examine the crankpin brasses. If they show marking all over, their adjustment is correct, but if the coloring matter is rubbed off at either end of the crankpin, the brasses do not fit the pin and must be filed and scraped until they bear equally on all parts of the pin.

731. Name some of the most frequent causes of pounding in engines.

Loose brasses; a loose thrust bearing; water in the cylinder; a loose piston; a slack follower plate, or junk ring; broken piston packing; the piston striking the heads; improper steam distribution; and pounding at the crosshead from various causes.

732. In the case of loose brasses, describe how pounding is produced, and how it may be remedied.

The pounding is produced by the striking of the journals against the sides of the brasses as the cranks are passing the centers and at the time the change of direction in motion of the piston takes place. If violent, the pounding will cause heating of the journal and boxes, especially at the crankpin. To remedy pounding of this nature, stop the engine and set up on the brasses gradually until the pounding stops, taking care that they are not set up too tight, else they will heat from friction. Shaft journals may be set up without stopping the engine, if they can be reached without danger of being caught in the machinery.

733. **When are boxes or brasses said to be brass and brass, or brass bound?**

When boxes or brasses are so worn down that the edges of the upper and lower halves are in contact and cannot be set up on the journal any farther, they are said to be **brass and brass, or brass bound.**

734. **Describe the method of procedure in repairing brass bound boxes or brasses.**

To repair brass bound boxes or brasses, the journal must be stripped, i.e., the cap and brasses must be removed from the journal. The edges of the brasses are then chipped or filed off, so as to allow them to be closed in. The amount to be taken off may be determined by trying the brasses on the journal occasionally or by calipering the journal with outside calipers and transferring the measurement to a pair of inside calipers, with which to measure the bore of the brasses as they are being fitted.

735. **How can the necessity of stripping brass-bound boxes be provided against?**

By reducing the two halves of the brasses so that they will stand off from each other when in place for a distance of $\frac{1}{8}$ inch to $\frac{3}{16}$ inch and filling this space with hard sheet-brass liners, from 20 to 22 Birmingham wire gauge in thickness each. Should the journal become brass bound, the cap may be slacked off and a pair of liners slipped out without the necessity of stripping the journal.

736. **Why is it desirable to avoid the stripping of journals whenever possible?**

Because it seems to be impossible in practice to put the journal brasses back just where they were before they were disturbed. In large engines it is almost always the case that journals will heat after being stripped, and they require special watching until they settle down on their proper new position relative to the journal.

737. What are keepers, or chipping pieces?

Some journal-boxes are fitted with **keepers, or chipping pieces,** which usually consist of a cast-brass liner, from ¼ inch to ½ inch in thickness, having ribs or ridges cast on one side, for convenience in chipping and filing. They are sometimes made of hardwood and are capable of being compressed slightly during the setting-up process. When the boxes are babbitted, the body of the box is occasionally made of cast iron, in which case iron liners and keepers are used instead of brass ones.

738. Which of the journals requires the greatest care and most constant watching, and why?

The crankpin. It is the journal most apt to heat from pounding. If the brasses are set up too tightly, friction develops; and on account of the comparatively small surface over which the friction is distributed, this pin requires the greatest care and constant watching.

739. Describe (a) a thrust bearing, or thrust block; (b) how pounding is caused by a loose thrust bearing; (c) how such pounding can be remedied.

(a) There are many types of thrust bearings, but the most common is the collar thrust, which consists of a series of collars on the shaft that fit in corresponding depressions in the bearing. In engines fitted with some types of friction couplings, there is a thrust exerted upon the shaft in the direction of its length, and the use of a thrust bearing of some kind is a necessity. (b) If the collars do not fit in the depressions snugly, the shaft will have end play and there will be more or less founding or **backlash** at every change of load on the engine. (c) This can be remedied by putting in a new thrust bearing and making a better fit with the shaft collars. In some thrust bearings the rings are adjustable and, in such cases, the end play may be taken up by adjusting the rings.

740. Explain how pounding in engines is caused by water in the cylinder and how it can be remedied.

Pounding in the cylinders is often caused by water, occurring as condensation or carried over from the boilers. If the cylinders are not fitted with automatic relief valves, open the drain cocks as quickly as possible and close down the throttle a little. If a boiler shows a tendency to prime, partly close the stop-valve on that boiler, thereby wiredrawing the steam a little, which will generally check priming.

741. **If the pounding is due to the piston's being loose on the rod, explain the cause and remedy in such case.**

A loose piston may be caused by the backing off of the piston-rod nut or key or the riveting may have become loose, permitting the piston to play back and forth on the piston rod. In such case the engine should be shut down instantly. After the engine is stopped, take off the cylinder head and set up on the piston nut as tightly as possible. As a measure of safetv a taper split pin should in all cases be fitted through the piston rod behind the nut, or a setscrew fitted through the nut.

742. **Explain the pounding caused by a slack piston follower plate, or junk ring, and how it can be remedied.**

This pounding is caused by the backing out of one or more of the follower bolts. Sometimes one of the follower bolts works itself out altogether and swashes about in the cylinder. This is a very dangerous condition, especially in a horizontal engine. If the bolt should get **end on** between the piston and cylinder head, either the piston or the cylinder head is bound to be broken. Therefore, in such a case, shut down the engine instantly, take off the cylinder head, remove the old bolt, and put in one having a tighter fit.

743. **Explain the pounding caused by broken piston packing and how it can be remedied.**

Broken packing rings and broken piston springs will cause a great noise in the cylinder, but it is more of a rattling than a pounding noise. There is not much danger of a serious breakdown from these causes, because the broken pieces remain within the space between the follower plate and the piston flange. Although they rattle around in the cylinder, they cannot get out or do much harm, aside from causing a leaky piston or slightly scoring the cylinder face. The remedy is, to replace the broken rings or springs as soon as possible.

744. Describe how pounding may be caused when the piston strikes the heads, and how it can then be remedied.

The piston may strike the heads as the result of the wearing away of the connecting-rod brasses. As the brasses are keyed up from time to time, the connecting-rod is lengthened or shortened, depending on the design, and this change in length destroys the clearance at one end of the cylinder by an equal amount. The remedy is to place sheet-metal liners behind the brasses, which will restore the rod to its original length. This will move the piston back or ahead and restore the clearance. The length of the connecting-rod should be measured from center to center of the bore of the crankpin and wristpin brasses. A rare cause for the piston's striking the head is the actual unscrewing of the piston rod from the crosshead, in cases when it is fastened by a thread and check-nut. To obviate any danger, the check-nut should be tried frequently. Every reciprocating steam engine should have the length of the stroke and the clearance space at each end of the cylinder marked on the guides. By this means the relative positions of the piston and the cylinder heads can always be seen at a glance.

745. Describe how pounding is caused by improper steam distribution, and how it can be remedied.

Improper distribution of steam is caused by the improper setting of the steam valve, or possibly its improper design. In the case of improper setting of the valve, insufficient compression, insufficient lead, cut-off too early, or late release, may all cause pounding on the centers. For practical reasons there must always be some lost motion at the wristpin, crankpin, and shaft bearings. In passing dead centers, the direction of pressure is suddenly reversed, and the piston rod, connecting-rod, and crank-shaft are suddenly thrown forward by the inrushing steam. It is this sudden changing of the lost motion from one brass to another, that causes an engine to knock in passing the centers, when compression is insufficient. By giving a sufficient amount of compression, the lost motion in the pins and journals is transferred gently from one side to the other before the crankpin reaches the dead center, so that when finally the live steam suddenly acts on the piston it cannot throw the rod forward. Too much compression causes great resistance to the motion of the crank and tends to increase the unsteadiness of the engine. Too much compression manifests itself by a dull, muffled sound in the cylinder or, on an indicator card, by a compression line rising above the steam line. Insufficient lead will cause pounding. The exact amount of lead to be given to prevent pounding can only be determined by an actual trial. In general, slow speed engines will require less lead than high-speed engines. The reason that insufficient lead causes an engine to pound is because the piston has then little or no cushion as it approaches the end of its stroke, and it is brought to rest with a jerk. A late release will produce a similar effect, as the pressure is retained too long on the driving side of the piston. The ideal condition is that the pressures shall be equal on both sides of the piston at a point in its travel just in advance of the opening of the steam port. A too early cut-off will expand the steam down too low—sometimes even below the back-pressure line. This condition will cause pounding, and should not be permitted to occur. A very high vacuum in a condensing engine will sometimes cause pounding by not permitting sufficient cushion for the piston.

746. The crosshead is a source of a great deal of thumping and pounding from various causes. Describe the most common cause, and the remedy.

One of the most common causes of pounding at the crosshead, is the getting loose of the piston rod. The remedy will depend upon the method of attaching the piston rod to the crosshead. The rod may pass through the crosshead with a shoulder or taper on one side of the crosshead and a nut on the other. In this case, the nut may work loose, which would cause the crosshead to receive a blow, first, by the nut on one side and then by the shoulder or taper on the other, at each change of motion of the piston. The remedy is to set up the nut. The rod may be secured to the crosshead by a cross key. Pounding will be produced if the cross key should work loose and back out, the remedy for which is to drive in the key. The end of the rod may be threaded and screwed into the crosshead, having a check-nut to hold the rod in place. In this case there is danger of the rod's slacking back and the piston's striking the rear cylinder head. The check nut should be closely watched.

747. **Name some of the other sources of pounding at the crosshead, and give the remedies.**

Another source of pounding at the crosshead is loose wristpin brasses, the remedy for which is to set up on the brasses, but not too tight. In the case of a crosshead working between parallel guides, pounding may be caused by the crosshead's being too loose between the guides. In this case the crosshead shoes should be set out. In the case of a slipper crosshead, pounding will result from the wearing down of the shoe, the remedy for which is to put a liner between the shoe and the foot of.the crosshead or to set it out with whatever means of adjustment are provided.

748. **What are the causes of pounding in the air pump?**

Pounding in the air pump is generally produced by the slamming of the valves, caused by an undue amount of water in the pump, which will usually relieve itself after a few strokes. However, the pump piston may be loose on the piston rod or the piston rod may be loose in the crosshead, either of which conditions will cause pounding. A broken valve may also cause pounding in the air pump; all of which must be repaired as soon as discovered.

749. **What causes pounding in a circulating pump?**

In a circulating pump of the reciprocating type, pounding may be caused by admitting too little injection water, and the pounding may be stopped by adjusting the injection valve to admit just enough water. It sometimes happens that the injection water is very cold, and to admit enough of it to stop the pounding in the circulating pump would make the feedwater too cold. In such case an air check-valve is often fitted to the circulating pump to admit air into the barrel of the pump as a cushion for the piston. A broken valve, the piston loose on the piston rod, or the piston rod loose in the crosshead will all cause pounding and should be repaired as soon as discovered.

750. **Enumerate the various causes that lead to the heating of bearings.**

Newly fitted brasses and journals. Refitted brasses and journals. Brasses set up too tightly. Brasses too loose. Warped and cracked brasses. Cut brasses and journals. Imperfectly fitted brasses. Not enough oil, or oil feed stopped entirely. Dirty and gritty oils, or oils of bad quality. Oil squeezed out of the bearings. Grit in the bearings. Journals too small, either in diameter or in length. Overloaded engine. Engine out of alignment. External heat. Brasses fitted too snugly between collars of journals. Springing of bedplates. Springing or shifting of pedestal or pillow-block.

751. **Why do some engineers consider it an error to make bearings adjustable?**

Because some engineers, as soon as they hear a pound or noise about an engine immediately conclude that some bearing is slack and tighten it up, which is one of the principal causes of hot bearings. The engineer should be fully convinced that the pounding is caused by slack brasses before setting them up.

752. **Then, why are not bearings made in the form of a hole through a solid support with a bushing of suitable metal in it?**

Because the bearing, however well designed and made, will in course of time wear somewhat, which makes it necessary that there should be some means of adjusting the brasses, so as to prevent the shaft from having a side movement when they are worn. Otherwise, a hole with a bushing of suitable metal in it would form the best possible bearing for a shaft.

753. **What attention should bearings receive on the part of the engineer, or oiler?**

Bearings, particularly those of large engines, should be constantly watched. The engineer or oiler should know at all times the condition of every bearing and oil cup. He should make frequent trips around the engine to ascertain if the oil cups are feeding and if they contain sufficient oil. While making his rounds he should feel with the palm of his hand the brasses of those bearings that have shown a tendency to heat and those that are most liable to heat, particularly the crankpins.

754. If a bearing shows an inclination to heat, what should be done to remedy the trouble?

The oil feed should be increased. If the bearing continues to get hotter, mix some flake graphite, flour sulphur, or powdered soapstone with the oil, and feed the mixture into the bearing, through the oil holes, between the brasses, or wherever else it can be forced in. A little aqua ammonia introduced into a hot bearing will sometimes check heating by converting the oil into soap, soap being an excellent lubricant. This is not possible, however, where mineral oils are used, as mineral oils will not saponify.

755. If after trying the remedies mentioned above, the bearing continues to grow hotter, what should be done?

The engine should be stopped and the cap nuts or key of the hot bearing should be slacked back and the engine allowed to stand until the bearing has cooled off. The cap nuts or key should be set up a little, but not too much, before starting, otherwise the brasses may be too loose, and cause excessive pounding.

756. What is the danger of increasing heating of a bearing with the engine running?

The brasses will be expanded by the heat and will grip the journals harder and harder the hotter they get. The condition of the bearing will grow worse as long as the engine is running, and may become so bad as to slow down and even stop the engine by excessive friction. The brasses and journals will be badly cut, and the engine will have to be laid up for repairs. If the brasses are babbitted, the white metal will melt out of the bearing, and, if there is not a spare set of brasses on hand, the engine will have to be laid up until the old brasses are rebabbitted, or until a new set is made and fitted.

757. If it is absolutely necessary in an emergency to keep an engine with a hot bearing running, how can this be done?

In a case of this kind the best judgment must be exercised as to how to proceed. After slacking off the brasses, about the best thing an engineer can do is to flood the inside of the bearing with a mixture of oil and graphite, sulphur, soapstone, etc., and the outside with cold water from buckets, sprinklers, or hose. Of course, the engine must be stopped as soon as the emergency has passed and the journal must then be stripped.

758. Why is it objectionable to hasten the cooling of hot bearings by pouring cold water upon them?

It may cause the brasses to warp or crack by unequal contraction. Putting water on a very hot bearing should be resorted to only in an emergency—when an engine **must** be kept running regardless of a spoiled pair of brasses. Water may be used on a moderately hot bearing without doing very much harm. When sprinklers are fitted to an engine, it is quite common to run a light spray of water on the crankpins when they show a tendency to heat, with very beneficial results.

759. How are cut bearings refitted?

The wearing surfaces of the brasses and journals must be smoothed off as well as possible; but if the grooves are very deeply cut, it will be useless to attempt to work them out entirely. If the brasses are very much warped or badly cracked, it will be best to put in new ones if any are on hand. If not, the old ones must be refitted and used until a new set can be produced, which should be done as soon as possible. If the journal is badly grooved, it should be turned in a lathe at the first opportunity and the brasses properly fitted.

760. Why should every precaution be taken to prevent the heating of bearings?

Because after a bearing has once been heated up sufficiently to cut the brasses and journal or to warp or crack the brasses, it is afterwards constantly in danger of heating up again, and the engine is thereby rendered unreliable and uncertain with regard to steady running.

761. Why are newly fitted bearings particularly liable to heat?

Newly worked surfaces of metal, when viewed through a powerful microscope, present the appearance of being a mass of fine needle points projecting outward. When the newly worked surfaces of two pieces of metal are rubbed together under pressure, the needle points of one piece engage with the needle points of the other piece and excessive friction is produced, the result being that the surfaces in contact are cut into grooves, which still further increases the friction and causes the metal to heat.

762. Describe the method of wearing down new bearings to prevent heating.

A new engine or one with new brasses and journals is run moderately, with regard to both speed and load, and with rather loose brasses, until the needle points on the newly worked surfaces of the metal are bent over. There will be little danger of the bearings heating thereafter from this cause if proper attention is given to their adjustment and lubrication.

763. What causes uneven bearing of brasses on the journals and what is the result?

For practical reasons there must be a little play between the brasses and their beds; this permits a slight movement of the brasses when pressure is exerted on them by the shaft; and although they may have been most carefully fitted, they require a certain amount of running to properly adjust themselves. This is especially the case with the bearings of large engines, and the same conditions will obtain every time the brasses are removed. It is almost impossible to put the brasses of a large bearing back again just where they were before the removal. Therefore, they should not be disturbed unless there is a positive necessity for doing so. The direct cause of heating in this instance is that the brasses do not bear evenly on the journal after the several parts of the bearing are assembled.

764. Why are refitted brasses and journals liable to heat?

Because the wearing surfaces of the brasses and journals having been newly worked or machined, the surface of the metal is in the needle stage, and, also because the brasses have not yet had a chance to adjust themselves to the journals and their beds. An engine with refitted bearings is in about the same condition as a new engine, so far as the bearings are concerned, and should be treated in the same manner.

765. Why are engine bearings liable to heat when the brasses are set up too tightly? How may heating from this cause be prevented?

The cause of heating of bearings when the brasses are set up too tightly is the abnormal friction that is produced by the binding of the brasses on the journals. In an attempt to stop a thump or a pound in an engine, or in making adjustments, care should be taken not to set up the brasses too tightly. As a matter of fact, hot bearings should never occur from this cause. Only a responsible person should be permitted to meddle with the adjustment of bearings.

766. Explain how heating of bearings is caused by brasses being too loose, and how such derangement can be remedied.

When the brasses are too loose, heating is caused by the hammering of the journal against the brasses when the crankpin is passing the dead centers. This derangement is remedied by setting up the cap nuts or key, but great care must be exercised not to set up too far, causing abnormal friction, with a hot bearing as a result.

767. Describe some of the methods used for setting up journal brasses.

One method is to set up the cap nuts or key nearly solid and then slack them back half way; if the brasses are still too loose, they are set up again and slacked back less than before, repeating this operation until a position is reached when there is neither thumping nor heating. Another method of setting up journal brasses is as follows: Fill up the spaces between the brasses with thin metal liners, say from 18 to 22 Birmingham wire gauge in thickness, and a few paper liners for fine adjustment; put in enough of them to cause the brasses to set rather loosely on the journal when the cap nuts or keys are set up solid. Run the engine for a while in that condition, then take out a pair of liners and set up solid again. Repeat this operation until the brasses have reached the point, when there is neither thumping nor heating, and there let them remain as long as this ideal condition exists. It may require a week or more, and with large engines longer, to reach the desired point, but it will be all the better to give the brasses time to adjust themselves. If this system of treating bearings is carefully carried out, there will be very little danger of their heating. In removing the liners, great care should be exercised not to disturb the brasses any more than is absolutely necessary. A pair of thin, flat-nosed pliers will be found useful in slipping out the liners. This method is preferable to the first one mentioned, because there is not so much danger of setting the brasses up too far.

768. **Why is heating of bearings caused by warped and cracked brasses? How can heating from this cause be remedied?**

Warped and cracked brasses will cause heating, because they do not bear evenly on the journal, and therefore the friction is not distributed over the entire surface, as it should be. The remedy will depend on the extent of the distortion of the brasses. If the distortion is not too great, the brasses may be refitted to the journals by chipping, filing, and scraping; but if they are twisted so that they cannot be refitted, new brasses should be fitted.

769. **Why do cut brasses and journals cause bearings to heat up, and how can heating from this cause be remedied?**

Cut and grooved brasses and journals are liable to heat up at any time on account of the undue friction produced by the roughness of the wearing surfaces. If the grooves in the journal are parallel and match the grooves in the brasses, the friction is not greatly increased; but if the journal is smooth and the brasses are grooved, the journal crushes the grooves in the brasses and becomes brazed or coated with brass, and then the coefficient of friction becomes high and heating results. The remedy for heating from this cause is to work the grooves out of the journal and brasses by filing and scraping as soon as possible after they occur.

770. **What may cause chronic heating of bearings which appear all right to the eye?**

In such cases the brasses do not bear fairly or sit squarely in their beds, and may not be square in the bearing. A crankpin brass must sit squarely on the end of the connecting-rod and the rod itself must be square. If the key, when driven, forces the brasses to one side or the other and twists the strop on the rod, it will draw the brasses slantwise on the pin and make them bear the hardest on one side or the other, thus reducing the area of the wearing surface. It is the same with the shaft bearings. If the brasses do not bed fairly on the bottom of the pillow-block casting or do not go down evenly, without springing in any way, they will run hot. Chronic heating of bearings is almost always caused by improperly fitted brasses. This defect should be looked for and remedied at once, if found to exist.

771. **Explain how heating of bearings is caused by brasses pinching the journals at their ends, and how the cause of such heating may be remedied.**

Brasses, when first heated by abnormal friction, tend to expand along the surface in contact with the journal; this would open the brass and make the bore of larger diameter, if it were not prevented by the cooler parts near the outside and by the bedplate itself. If the brass has become hot quickly and excessively, the resistance to expansion produces a permanent set on the layers of metal near the journal, so that on cooling, the brass closes and grips the journal; it will then set up sufficient friction to heat again and expand sufficiently to ease itself from the journal, and so long as that temperature is maintained the journal runs easily in the bearing. This is why some bearings always run a trifle warm and will not work cool. A continuance of heating and cooling will set up a mechanical action at the middle of the brass, which must eventually end in cracking it, just as a piece of sheet metal is broken by continually bending it backward and forward about a certain line. This cause of heating may be prevented by chipping off the brasses at their edges parallel to the journal.

772. **Explain the causes of a bearing's becoming dry, and the result of it.**

The two principal causes of a bearing's becoming dry are an oil cup that has stopped feeding, either by reason of being empty or by being clogged up from dirt in the oil, and oil holes and oil grooves stopped up with accumulated dirt and gum. The result will be a very hot bearing in a very short time. By the exercise of reasonable care these conditions can be prevented.

773. **What are the effects produced upon a bearing by an insufficient oil supply?**

The effects produced upon a bearing by an insufficient oil supply are similar to that of no oil. Of course it will take longer for a bearing to heat with insufficient oil than with none at all, and the engineer has more time in which to discover and remedy the difficulty. A steady feed, a drop at a time, is what a journal requires.

774. **What precautions should an engineer take to prevent the heating of bearings caused by dirty and gritty oils and oils of bad qualities?**

There is a great deal of dirt in lubricating oil of the average quality. Therefore, all oil should be strained through a cloth or filter, and oil tubes and channels should be thoroughly cleaned out frequently. The heating of bearings, caused by the use of oils of bad quality, is not so easily disposed of, however. About the only safe way to meet this trouble is to pay a fair price to a reputable dealer for oil that is known to be of good quality, unless the purchaser is an expert in oils. Cheap combination oils, and gummy oils, which choke up the oil channels and glue the brasses and journals together over night, should be avoided.

775. Explain how bearings are caused to run dry and heat up, the oil being squeezed out at the ends of brasses, and how this difficulty may be remedied.

Bearings carrying very heavy shafts sometimes refuse to take the oil, or if they do it is squeezed out at the ends of the brasses or through the oil holes, when the journal will run dry and heat. The great weight of the shaft causes the journal to hug the bottom brass so closely that the oil cannot penetrate between them, or, if it does, it is immediately rejected. This difficulty may be met by chipping oil grooves or channels in the brasses.

776. Explain how oil grooves or channels are chipped in brasses.

A round-nose cape chisel, slightly curved, is generally used for this purpose, taking care to smooth off the burrs made by the chisel; a steel scraper or the point of a flat file will do this. The grooves are usually cut into the brass in the form of a V if the engine is required to run only in one direction; if it is to run in both directions, the grooves should form an X. In the first instance care must be taken that the grooves spread out from their junction in the same direction as that in which the journal runs. The oil grooves may be about ¼ inch wide and ⅛ inch deep and semicircular in cross-section.

777. What causes the presence of grit in bearings? In what way does grit affect the running of the engine, and what precautions should be taken to prevent this condition?

The causes of the presence of grit in bearings are innumerable; therefore, it is only possible to mention a few of them. The machinery of coal breakers, stone crushers, and similar industries is especially liable to be affected by grit. Work done on a floor over an engine shakes dirt down upon it. If piles of red-hot clinkers and ashes are wetted down with buckets of water, the water is instantly converted into a large volume of steam that rises, carrying with it large quantities of small particles of ashes and grit that penetrate into nook and cranny, and find their way into the bearings, if the fireroom and engine room communicate.

If emery, emery cloth, Bath brick, or other gritty cleaning material is used around a bearing, it is sure to get inside. The presence of grit is often the cause of a hot bearing. The following precautions should be taken: All floors over engines should be made dust-proof. Throwing large quantities of water on hot clinkers and ashes should be stopped; sprinkle them instead and close the fireroom door while the fires are being cleaned and the ashes handled. If emery, or other gritty cleaning material is used, all open oil holes should be plugged with wooden plugs or bits of clean cotton waste. This precaution against grit getting into the bearings may also be taken when the engine is stopped for any length of time. Plaited hemp or cotton gaskets should also be laid over the crevices between the ends of the brasses and the collars of the journals of every bearing and kept there while the engine is standing still. Even where dust-proof bearings are used, the engineer should take every precaution possible to keep grit and dirt out of them.

778. **Why will journals heat when too small?**

Because in practice only a certain amount of pressure per square inch of area can be sustained by a bearing before the friction reaches the point that will cause heating.

779. **On what does the pressure that a bearing will sustain per square inch of area of rubbing surface without heating depend?**

It depends on the materials of which the journal and brasses are composed, the fineness of their finish, the accuracy of their fit, the adjustment of the brasses, the rubbing speed of journals in brasses, and the lubricant used.

780. **Explain why it is necessary to make engine journals large enough to distribute the friction over a sufficient area of surface.**

Pressure and friction have a direct relation to each other. Less friction is produced per square inch of surface by a long journal than by a short one of equal diameter with the same total pressure; therefore, a long journal is not nearly as liable to heat as a short one of the same diameter, and a journal of large diameter is not as liable to heat as one of small diameter of equal length. The total amount of friction of two bodies in contact depends on the pressure of the one on the other and is nearly independent of the area of the surface of contact; therefore, it is necessary to make engine journals large enough to distribute the friction over a sufficient area of surface.

781. What is the cure for a bearing that heats constantly, on account of being too small?

The cure is to make it larger if circumstances permit it to be done. If this is impossible, the best of lubricant must be used, and if necessary, water must be run constantly on the bearing.

782. Why are bearings liable to heat when an engine is overloaded, and what is the remedy?

The effect produced by overloading an engine is similar to that of the journals being too small. The pressure on the brasses being increased to a point beyond that for which they were designed, the friction exceeds the practical limit and the bearing heats. The only remedy is to reduce the load on the engine to the amount it was intended to stand.

783. Why are bearings liable to heat when the engine is out of line, and how can this be remedied?

If an engine is not in line, the brasses do not bear fairly upon the journals. This will reduce the area of the wearing surfaces in contact to such an extent that the friction is in excess of the practical limit, which necessarily will cause heating. If the engine is not greatly out of line, the difficulty may be remedied by filing and scraping down the parts of the brasses that bear most heavily on the journal. If this does not stop the heating, the engine should be lined up.

784. If crosshead guides heat up and continue to give trouble, what may be the cause, and how can it be remedied?

Crosshead guides that are out of line are apt to heat, and they will continue to give trouble until the defect is remedied. The guides may also heat because the gibs may be set up too much. If such is the case, they should be slacked off. The danger of guides heating may be lessened by chipping zigzag **oil grooves** in their wearing surfaces and by attaching to the crosshead, **oil wipers,** made of cotton lamp wicking arranged so as to dip into oil reservoirs at each end of the guides if they are horizontal, and at the lower end if they are vertical. These wipers will spread a film of oil over the guides at every stroke of the crosshead, which will keep them well lubricated.

785. **Explain how external heat causes bearings to run hot, and how this difficulty may be remedied.**

If the engine is placed too near furnaces or an uncovered boiler, or in an atmosphere highly heated by uncovered steam pipes or by other means, the heat of the atmosphere will expand the brasses until they nip the journal, which will generate additional heat and cause further expansion of the brasses, and so on until a hot bearing is the result. If the engine is placed close enough to a furnace to cause heating from that source, a tight partition should be put up, if possible, which will also prevent dirt and grit from the fireroom getting into the bearings. If the boilers, steam pipes and cylinders are uncovered, they should be covered with some good non-conducting material. A ventilating fan could possibly be rigged up to advantage. Other remedies depend upon the conditions and require the judgment of the engineer.

786. **Why are bearings liable to run hot when the brasses are too long, and how may this difficulty be remedied?**

If the brasses are too long and bear against the collars of the journal when cold, they will most surely heat after the engine has been running a while. Bearings will always heat up a little and the brasses will be expanded thereby, which will cause them to bear still harder against the collars. This, in turn, will induce greater friction and more expansion of the brasses. This evil may be remedied by chipping or filing a little from each end of the brasses until they cease to bear against the collars while running. A little side play also promotes a better distribution of the oil and prevents the journal and brasses from wearing into concentric parallel grooves.

787. Why are bearings liable to heat when the bedplate of an engine is not rigid enough or if it is sprung, and how can this difficulty be remedied?

If the bedplate of an engine is not rigid enough to resist the vibration of the moving parts, or if it is sprung, the engine will be thrown out of line. The brasses will then not bear fairly on the journals, which will reduce the area of the wearing surfaces in contact to such an extent that the friction is in excess of the practical limit, which will cause heating. In such case it will do no good to refit the brasses unless the engine bed is stiffened in some way and levelled up. The form of the bedplate and the surrounding conditions must suggest the best way to remedy this difficulty.

788. Why is a bearing liable to heat when the pedestal or the pillow-block is sprung or shifted, and how can this be remedied?

The effect of the springing or shifting of the pedestal or pillow-block is similar to the springing of the bedplate; that is, the bearing will be thrown out of line and heat up. As the pedestal is usually adjustable, it is an easy matter to readjust it, after which the holding-down bolts should be screwed down hard. If a pedestal is not stiff enough to resist the strains upon it and it springs, measures should be taken to stiffen it. The method to be used can only be determined on the spot.

LUBRICATION

789. How may lubricants be classified?

Lubricants may be divided into three classes, namely, **animal**, **vegetable**, and **mineral**. There are also lubricants that are composed of a combination of two or more of the above primary classes, which practically form a fourth class. The animal and vegetable oils are called **fatty** oils; the mineral oils are called **hydrocarbon** oils.

790. On what does the value of a lubricant depend?

The value of a lubricant depends on the amount of greasy particles it contains, or its **viscosity**.

791. Mention some of the desirable properties a good lubricating oil should possess.

Some of the desirable properties of a good lubricating oil are: It should reduce friction to a minimum. It should be free from acids and free alkalies. It should not become gummy, rancid, or otherwise altered by exposure to the air; and it should be odorless. It should stand a low temperature without solidifying or depositing solid matter. It should be entirely free from grit and all foreign matter. It should be especially adapted to the conditions as to speed and pressure of the rubbing surfaces on which it is to be used. All first-class lubricants possess these properties to a greater or less degree, and each of them is adapted to its own particular class of work. They are also of all degrees of fluidity and solidity.

792. How can an engineer who is not an expert judge of lubricants select a lubricant best suited to his practical needs?

The best he can do is to procure from **a reputable** dealer several samples of oil or grease that in his judgment are best suited to the machinery he has in charge, taking care to select light-bodied oils for light and fast running machinery and to grade his selections down to suit the size and weight of the journals and the work they have to do. Then he should run the machinery for a stated length of time with each oil, carefully noting the results obtained by each. The one that will obtain the best results is the one he should hold to until he has good reason to believe that he can get a better one. He might try another lot of samples in the same way as before, and so on until he finds the best one for his purpose that the market affords, and at the same time he will acquire valuable experience with lubricants. These experiments should be made with well-known standard brands of lubricants only, otherwise the engineer will waste much time without gaining any benefit.

793. **Explain how samples of lubricants for trial should be selected by the engineer.**

In selecting the samples for trial the engineer should examine them carefully and compare one with the other; he should note their color and transparency; rub some of each between the fingers and thumb or on the palm of the hand; note if the sample is smooth and oily and contains no grit; pour a few drops on a sheet of tin or a piece of glass and hold the tin or glass at different angles and note how it flows and whether it leaves any residue or gum in its track; examine it with a strong magnifying glass for foreign substances; smell it, and if it is rancid or has a very offensve odor, reject it.

794. **What are animal oils?**

Animal oils are those derived from the fats of animals and fish.

795. **Name and describe the animal oils used as lubricants.**

The animal oils used as lubricants are: Lard oil; tallow oil; neatsfoot oil; horse-fat oil; sperm oil; whale oil; seal oil; and shark oil. Pure lard oil is the best lubricant for ordinary machinery; but it has the disadvantage of congealing in cold weather. The tallow oil is very similar to lard oil. Horse-fat oil is sometimes used in place of tallow, but its odor is offensive. Clarified neatsfoot oil is an excellent lubricant for light machinery. Of fish oils, sperm is the best lubricant, but it is scarce and too high-priced for general use. It is used for oiling delicate machinery. Whale and porpoise oils are sometimes used in place of sperm oil, but they are not quite so good. Seal and shark's liver oils are used as adulterants. Menhaden fish oil should not be used as a lubricant, as it quickly turns rancid and gums.

796. What are vegetable oils?

Oils derived from the fruits, seeds, and nuts of trees and plants.

797. Name and describe the leading vegetable oils used as lubricants.

The leading **vegetable oils** used for lubricating purposes are: Olive oil, rape-seed oil (colza oil), cottonseed oil, castor oil, and palm oil. They compare very favorably with animal oils as lubricants, and several of them are excellent for that purpose. The olive oil is probably the best vegetable oil used for lubricating machinery. Castor oil and cottonseed oils are more liable to gum than pure olive oil. Palm or cocoanut oil soon becomes rancid and in that condition it is not a good lubricant.

798. What are mineral lubricating oils?

Mineral lubricating oils are oils distilled from bituminous shale and (more commonly) from the residuum of crude petroleum after the volatile oils and illuminating oils have been distilled off. They are produced at various temperatures up to 572° F.

799. Name some of the mineral lubricating oils.

Solar oil, mixed oil, spindle oil Nos. 1 and 2, machine oil Nos. 1 and 2, pale cylinder oil, dark cylinder oil, and vulcan oils. There are many other mineral lubricating oils on sale under different names, each manufacturer naming his own product to suit himself. All the mineral oils, if pure, are excellent lubricants, each one being adapted to its specific purpose for light, medium, and heavy machinery, and for cylinders.

800. How are mineral lubricating oils graded?

They are graded according to their specific gravities.

801. What is the burning point of these mineral lubricating oils?

The **burning point** of the machine oils is about 435° F. and up, and that of the cylinder oils, 525° F. and up.

802. Can the purity or value of a mineral lubricating oil always be judged by its color?

No. A dark-colored oil may be purer than a light-colored one, and too much stress should not be laid upon the color in selecting a mineral oil.

803. What are compounded oils?

As a rule, they are compounded of thin, light oils, and a variety of substances to produce an artificial body that adds nothing to their lubricating properties. Most of them are of a gummy nature and not fit to be used as a lubricant. If mineral oils are used as the basis of these compounded oils they are liable to have a low flash point, which makes them totally unfit for use in cylinders.

804. Is there any economy in the use of cheap lubricants?

No. A cheap lubricant costs less per gallon, but it takes more gallons to do the same work. Now that excellent oil filters are to be had, the drip oil can be filtered and used over again, and there is no necessity for using cheap oils.

805. Classify the various greases used as lubricants.

Greases are divided into three classes, namely, **compounded, set or axle,** and **boiled or cup.**

806. Describe compounded greases.

Compounded greases are made by mixing cheap oils with fats, paraffin, and the various waxes. They soon become rancid, in which state they become friction producers rather than lubricants. The engineer should avoid these greases, even though they are cheap.

807. Describe set, or axle, greases.

Set or axle greases are mixtures of low-grade oils and fats converted into grease by the application of lime. They are used principally for lubricating axles of vehicles and the like, and are familiarly known as **cart greases.** They are unfit to use in the bearings of engines.

808. Describe boiled, or cup, greases.

Boiled, or **cup, greases** are produced chemically and are not simply mechanical mixtures as are the others.

They are perfectly neutral and will remain so indefinitely. They are made by saponifying fats and fatty oils with lime and dissolving the soap in mineral oil. They are well adapted for engine lubrication. In this class there is a series of greases that are made by saponifying the fats and fatty oils by means of caustic soda. These greases are good lubricants if properly made, but they are apt to contain either an excess of alkali or an excess of acid. In either case they are liable to be injurious to the bearings. Free acids or alkalies may be detected by the litmus-paper test.

809. Name some of the boiled, or cup greases.

Nos. 1 to 4 cup greases, Nos. 1 to 3 Albany greases, sponge greases, crankpin greases, gear greases, lubricating packing, plumbago and graphite greases.

810. What are the solid lubricants?

They are: **graphite, soapstone, sulphur, mica,** and **metaline.** They may properly be classed under the general head of mineral lubricants.

811. Explain how graphite is used for lubrication.

Graphite, called also **plumbago** and **black lead,** is used for lubrication either in the form of a powder, flaked or compressed into bushings, or by being mixed with wood fiber and solidified in molds by pressure; this latter is called **fiber graphite.** After being removed from the molds, the forms are thoroughly dried and then saturated with a drying oil, after which they are exposed to a current of hot dry air to oxidize the oil and to harden the mass. When hard they may be worked the same as metal. **Fiber graphite** is claimed to be self-lubricating. The powdered and flaked graphites are used to mix with greases for heavy journals and also to mix with the ordinary engine oils to cool a hot bearing. When graphite is used as a lubricant, the journal becomes covered with a thin coating of graphite, which reduces friction to a minimum.

812. Describe how soapstone, sulphur, and mica are used in connection with lubricating oils and greases.

Soapstone, sulphur, and **mica,** in the form of powder, are sometimes mixed with oils and greases to improve their lubricating qualities for heavy and hot journals.

Sheets of **mica** pressed together and held firmly in a casing have been used instead of brasses with fair success.

813. What is metaline and how is it used?

Metaline consists of small cylinders of graphite fitted into holes drilled in the surface of the bearing; it is said to require no other lubrication.

814. What is the object of lubricating the bearings of an engine?

The object of lubricating the bearings of an engine is to reduce the friction of those parts that rub against one another to a minimum and to prevent the rubbing surfaces from becoming hot and seizing, thereby permanently damaging the bearings. The lubricant forms a thin film between the rubbing surfaces, and thus prevents the rubbing surfaces from coming into direct contact with one another.

815. Why are mineral oils preferable to animal and vegetable oils for lubricating high steam pressure engines, especially for lubricating pistons and slide valves?

Because the mineral lubricating oils are not carbonized by high-pressure steam as readily as are animal and vegetable oils. Moreover, animal and vegetable oils are decomposed by the great heat of high-pressure steam and form stearic, palmitic, and oleic acids. These acids when hot readily attack iron, steel, copper, and its alloys; therefore, cylinders, pistons, etc., are eaten away when fatty oils are used for lubricating them. These acids are particularly destructive to steam boilers when the exhaust steam is condensed and used as feedwater, as in the case of surface condensers.

816. Why is it particularly necessary to use high-grade oils for lubricating piston and slide valves?

Because the higher the temperature the less is the lubricating power of the oil or grease used. Therefore, high-grade cylinder oils only should be used and the flash point should not be lower than 400° F., and the burning point not lower than 525° F.

817. What pieces of apparatus are required to enable the engineer to make simple tests of lubricants and assist him in the selection of same?

The pieces of apparatus required to make simple tests of lubricants consist of an ordinary tin or iron pan 8 or 10 inches in diameter and 3 or 4 inches deep; a metal cup about the size and shape of an ordinary tumbler; a high-grade thermometer that will measure at least 500° F.; a couple of quarts of clean white sand; a half-dozen clear, white glass ½-pint bottles; a large sheet of tin or plate of glass, preferably a plate of glass; a sheet each of red and blue litmus paper; a common thermometer; a quart of gasoline; a few pounds of ice; a pound or two of rock salt and about the same quantity of sal soda (washing soda); a small iron boiler or saucepan; a small quantity of caustic soda or concentrated lye; a pane of glass painted black on one side with a mixture of shellac varnish and lampblack, and a small tin funnel.

818. Describe how lubricating oil or grease should be tested for acids and alkalies.

Dissolve about a teaspoonful of the oil or grease to be tested in five or six times as much of boiling water, in which steep a piece of red litmus paper; if the litmus paper remains red after having been soaked in the mixture for a considerable length of time, the oil or grease is **acid.** If the color of the paper turns to dark blue quickly, the oil is **alkali.** If it changes color very gradually to a light blue, the oil is **neutral.** As a check on the above test, try the mixture with a piece of blue litmus paper in the same way. If the color of the paper does not change, the oil is **alkali.** If the paper turns red quickly, the mixture is **acid;** but if the paper changes very gradually to a pale red, the solution is **neutral.**

819. Explain how lubricating oils may be tested for viscosity.

Pour a few drops of each sample of oil upon the large sheet of tin or glass while the sheet is perfectly level, then raise one end of the sheet gently about 1 inch and support it in that position; watch the drops of oil running down the inclined sheet. The oil that reaches the bottom of the sheet **last** ranks highest in **viscosity.** Although this is only a comparative test, it will enable the engineer to select the oil best adapted to his purpose from a number of samples. After making the selection, it would be well to try the precipitation test on it for artificial viscosity.

820. How can an engineer test greases for viscosity?

About the only convenient method for the engineer to do this is by rubbing some of the grease between his fingers and thumb or in the palm of his hand, noting the result. After some practice he will be able to judge approximately the viscosity of the sample.

821. Explain how a flash and burning test of lubricating oil can be made.

Pour some of the oil that is to be tested into the metal cup until it is nearly full; place the cup in the pan and surround the cup with sand until the pan is filled with it; place the pan and the contents on a hot stove, or in any other convenient place for heating it; immerse the bulb end of the high-grade thermometer in the oil in the cup and watch the rise in temperature; when it reaches 300° pass a lighted match slowly across the top of the cup; repeat this every 2 or 3 degrees rise in temperature until the vapor arising from the oil ignites with a flash, then note the temperature as indicated by the thermometer; this is the **flash point.** Continue the test until the oil ignites and burns on the surface. When that occurs the reading of the thermometer gives the **burning point.**

822. Explain how the cold test or the test for the congealing point of lubricating oil can be made.

Partly fill the metal cup with the oil to be tested; place the cup in the pan; fill the pan around the cup with cracked ice mixed with rock salt and sal soda; cover the apparatus with a piece of bagging or blanket and keep it covered until the oil in the cup is congealed; then remove the freezing mixture from the pan and fill the pan with hot water; when the oil in the cup commences to melt, immerse the bulb of a thermometer into it and note the temperature; this temperature is the **congealing point.**

823. How can lubricating oil be tested to ascertain whether it is pure mineral oil, or mixed with animal or vegetable oil?

Place about a pint of the oil in the small iron boiler or saucepan and add 1 or 2 ounces of caustic soda or concentrated lye; boil the mixture for ½ hour and then set it aside to cool. A tablespoonful of chloride of sodium (common salt) thrown into the mixture while cooling will hasten the process. When thoroughly cool, examine the mixture; if the surface is covered with soap, the oil contains animal or vegetable fats; otherwise it is pure mineral oil. This is known as the **saponification test** of oil.

824. How can the presence of mineral oil be detected when mixed with animal or vegetable oil?

The presence of mineral oil when mixed with fatty oils may be detected by pouring a drop of the mixed oil upon the sheet of blackened glass and holding the glass at various angles to the light; if it shows rainbow colors, it contains mineral oil.

825. How can lubricating oil be tested for the purpose of ascertaining whether the oil contains paraffin, waxes, gums, etc.?

Place an ounce of the oil to be tested in a ½-pint bottle, pour 2 ounces of gasoline into the bottle on top of the oil, and shake the bottle until the oil is dissolved by the gasoline; then allow the mixture to settle. If there is any considerable amount of precipitation or sediment in the bottle, it indicates that the oil in it has been treated to produce artificial viscosity. This is known as the **precipitation test.**

826. How can mineral oil be tested for the purpose of ascertaining if the oil contains sulphur?

Pour a small portion of the oil into the metal cup; place the cup in the pan and surround the cup with sand until the pan is filled with it; place the pan and contents on a hot stove, or in any other convenient place to be heated; heat the oil to 300° F. and maintain that temperature for about 15 minutes; after cooling, if the sample is considerably darker in color than the original oil, it is unfit to use in cylinders or on hot bearings.

827. What are lubricators and how are they classified?

Lubricators are devices used for the automatic lubrication of machinery and may be divided into two general classes, **bearing lubricators** and **steam lubricators.**

828. Into what classes may bearing lubricators be divided?

Bearing lubricators may be divided into **plain** and **sight-feed lubricators,** which can only be used for oil, and **grease cups,** which are built to use grease. These lubricators are applicable only to the lubrication of bearings.

829. Describe a plain bearing lubricator.

This is the simplest form of lubricator made for automatic lubrication. It consists of a body fitted with a central tube and a removable cover. The oil contained in the body is carried over into the central tube by a wick made of a few strands of lamp wick. This oiling device is very simple, but unreliable, and the oil feed cannot be adjusted, as the flow of oil is not in plain sight.

830. Describe the sight-feed bearing lubricator.

This lubricator consists of a glass oil reservoir having a central tube with a valve seat inside of it and at its lower end. A valve which can be locked in any position by a locknut, serves to regulate the flow of the oil. The oil enters through a hole in the lower end of the central tube. The drops of oil show plainly in a side-feed glass. The upper cover has a hole in it through which the reservoir is filled; a movable cover is fitted over the hole to keep out the dust. The oil is generally fed by gravity. Various attachments are used for conveying the oil from a stationary sight-feed lubricator to moving parts, as crankpin, eccentric, and wristpin.

831. Describe grease cups used for the lubrication of bearings.

Grease cups are made in various ways and either as **plain** or **compression** cups. In a plain cup the grease flows down only by gravity as the heat of the bearing melts it; to assist the grease, it is good practice to put a piece of small copper wire in the hole through which the grease leaves the cup. A compression grease cup may be hand-operated or spring-operated. By screwing the cap down by hand over the base, the grease is forced out. Spring-operated compression grease cups have a piston, on top of which is placed a spring that continually forces out the grease. In most of them the rate of flow can be regulated by a suitable valve.

832. What is the purpose of steam lubricators, and into what three classes may they be divided?

The purpose of the **steam lubricator** is to lubricate the moving parts in contact with the steam. They may be divided into **mechanical, water-displacement,** and **hydraulic** lubricators.

833. Describe the mechanical steam lubricator and its operation.

This class of steam lubricator generally has the form of a force pump. It may be operated by hand, in which case its action is intermittent. When a mechanical lubricator is operated continuously by some moving part of the engine, its action is automatic. A hand-operated mechanical lubricator is generally fitted to the main steam pipe close to the throttle, only as an emergency device, to be used when the automatic lubricator is out of order.

834. Describe the water-displacement lubricator and its action.

The simplest form of a water-diplacement lubricator consists of a cylindrical shell provided with a central tube; a cap through which the lubricator is filled; and a shank for attaching it in a vertical position to the steam chest or steam pipe. A valve controls the communication between the lubricator and the engine. The action is caused by condensation of steam in the reservoir containing the oil; the oil being lighter than water floats on top and flows over the edges of the central tube and runs by gravity into the steam pipe. The objectionable features of this lubricator are that the flow of oil is not readily controlled and that there is no indication when the lubricator stops working. To overcome these objections, sight-feed water-displacement lubricators are used. They differ from the simpler form of indicator only in construction, the principle of action being the same. All water displacement lubricators belong to the **single connection-type.** There is only one connection to the steam pipe and the oil must pass through the same passage as that through which the steam is admitted. These lubricators use a **down-feed,** that is, the oil is discharged downward from the feed nozzle.

835. Describe the hydraulic lubricator and its action.

Hydraulic lubricators are made in two styles, **single-connection** and **double-connection.** In the **single-connection** lubricator the oil must pass through the same passage through which the steam is admitted. In a **double-connection** lubricator there are two connecting pipes to the steam pipe, the steam being admitted through one pipe and the oil leaving the lubricator through the other. The steam admitted flows into a condenser. In some lubricators the condenser is an independent vessel. The water in the condenser flows through a pipe into the bottom of the oil reservoir and forces the oil to the top, exerting a hydrostatic pressure on the bottom of the oil. The oil flows through a pipe into a nozzle located in the bottom of the sight-feed glass and out of the nozzle into the glass. Oil being lighter than water, the drops of oil ascend to the top of the sight-feed glass, which is filled with water. The oil then flows through the connections and valve into the steam pipe. There is an equal steam pressure on top of the water in the condenser and in the sight-feed glass, so that the pressure forcing the oil out of the lubricator is only that due to the hydrostatic head. The rate of flow of the oil through the nozzle in the bottom of the sight-feed glass can be regulated by means of a needle valve. A gauge glass is fitted to show the amount of oil in the lubricator. These lubricators have an **up feed;** that is, the drops of oil flow upward in the sight-feed glass.

836. Why should double-connection lubricators never have one connection attached to the steam pipe between the throttle and the boiler and the other between the thottle and the engine?

Because if the lubricator is connected in this manner, upon closing the throttle there will be full steam pressure on the condenser and none on the sight-feed glass. In consequence, the lubricator will very rapidly be emptied, the steam pressure forcing all the oil out into the engine. If circumstances require the connection to be made in this manner, a special locomotive double-connection sight-feed lubricator should be used. Such a lubricator is made in such a manner that the oil cannot leave the reservoir when the throttle is closed.

TYPES OF ENGINE

837. What are the two principal factors that dictate the use of the vertical engine and why are these the controlling features?

The two controlling factors that dictate the use of the vertical engine are (1) available floor space for the engine and (2) size of engine. The horizontal engine requires more floor space than the vertical engine and, in localities where property is valuable, the vertical engine is used, although it is more expensive and less accessible than the horizontal engine. As to the second reason, in very large horizontal engines, and particularly with the low-pressure cylinder of compound engines, the problem of supporting the weight and preventing cutting by massive low-pressure pistons becomes one of great magnitude. This bad feature of the horizontal engine is entirely overcome by making the engine vertical; the weight of the piston is then borne by the shaft bearings.

838. Are there any means of supporting the weight of large pistons of horizontal engines to prevent cutting? Explain them.

Yes. Many devices have been tried to support the weight of large pistons and some of them have merit, but many engineers believe the vertical engine to be the best solution of the problem. Some of the devices used are: tailrods having crossheads running on external guides; pistons having a steam pocket underneath them, into which steam is admitted through a small hollow tailrod; forged steel-plate pistons having broad composition shoes riveted to the lower circumference, the shoes projecting into recesses formed in the heads; and very broad pistons in which the weight of the piston does not exceed 3 pounds per square inch of projected area.

839. Mention some of the disadvantages of the vertical engine.

The vertical engine is much more inaccessible than the horizontal engine for oiling, inspecting, and repairing. In some vertical engines it would be necessary to dismantle the whole machine to remove the crank-shaft, although the specifications usually demand that it be possible to remove the crank-shaft bearings when the shaft is raised ¼ inch. The vertical engine costs on an average about 12 per cent. more than the horizontal engine. Owing to its inaccessibility and the labor and exertion required to reach its various parts, the vertical engine will not receive the same care and attention that the horizontal machine will. This should not be the case, but it is so, nevertheless. The vertical engine requires quite a high building, because extra room is needed to draw out the piston and piston rod. If the engine is large, a substantial crane or other means of handling the various parts is necessary. In large plants where vertical engines are used it is necessary to construct galleries around the house so that the various units can be visited for inspection and oiling.

840. Mention some of the advantages the horizontal engine has over the vertical engine.

The horizontal engine is the cheaper engine, is much more accessible for repairs, oiling, and inspection, and can be cared for by a man physically incapacitated to handle a vertical engine.

841. Why is it necessary to exercise especial care in the design of the vertical engine to free of water all parts coming in contact with the live steam and to prevent water pockets?

Unless such care in the design of the vertical engine is exercised, its economy will fall below that of the horizontal engine. This is especially true in the four-valve type, which type when embodied in the horizontal engine is almost self-draining. The vertical design does not so readily lend itself to drainage and therefore requires especial care in this respect.

842. Why is the mechanical efficiency of the vertical engine from 2 to 3 per cent. higher than that of the horizontal engine?

Because with an equal measure of care with regard to balancing, the vertical engine will operate more smoothly than the horizontal engine; this is due to the fact that the unbalanced vertical force acts vertically through the machine and foundation, while the unbalanced horizontal force is close to the foundation and is counteracted by two heavy masses—the foundation below and the engine above.

843. Describe the combined vertical and horizontal engine.

It is a combination of the horizontal and vertical engine. This engine is usually made a **compound,** in which the low-pressure cylinder is vertical, while the high-pressure cylinder is placed horizontal. Both cylinders may act on one crankpin, thus making a compact machine having all the advantages of two cranks at right angles. This type of machine has been made in very large units and used for direct-connected electric service and reversing rolling-mill service.

844. What are the two distinct types of automatic cut-off engines?

They are, the **positive automatic cut-off,** in which the main or cut-off valve closes the ports by positive motion derived from some part of the engine, usually an eccentric on the main shaft, and the **releasing-gear cut-off,** in which the main valve or cut-off valve is made to close the admission port by means of vacuum pots, weights, springs, steam pressure, or other sufficient means.

845. At what speeds are the releasing-gear engines usually operated?

The best builders do not advise speeds higher than 100 revolutions per minute for engines up to 500 horsepower, 85 revolutions per minute up to 2,000 horsepower, and 75 revolutions per minute up to 5,000 horsepower, although small releasing-gear engines have been run at 150 revolutions per minute.

846. Why is it not advisable to run the releasing-gear engines at speeds higher than those given in answer 845?

Because to run **releasing-gear** engines at higher speeds satisfactorily the machines must be especially constructed and heavily built, they require a larger quantity of oil, and there is little insurance against shut down due to breakage or heating.

847. What type of engine should be chosen for conditions requiring high speed and economy?

For conditions requiring high-speed and economy the **positive automatic cut-off engine** should be chosen, as these machines can always be run at speeds not determined or limited by the construction or operation of the valve gear.

848. How does the positive automatic cut-off engine compare with the releasing-gear engine with regard to economy?

The economy of the **positive automatic cut-off engine** with one valve is only about 75 per cent. of that of a **releasing-gear automatic cut-off engine** of equal grade. There are, however, some positive automatic cut-off engines of the **four-valve** type in which the cut-off valve is mounted on the main valve and is positively driven by a shaft governor; in such an engine the economy of steam is nearly equal to that of the **releasing-gear engine.** They are not usually run at as high speeds as the one-valve positive automatic cut-off engine, owing to some complications of the valve gear. The **four-valve** type of given cylinder dimensions is somewhat more expensive than the **releasing-gear** engine, which, in turn, is considerably more expensive than the **one-valve** automatic engine. But for equal powers, the releasing gear engine may cost more than the four-valve type.

849. Compare the releasing-gear engine with the positive-gear engine regarding accessibility and oiling.

The releasing-gear engine is more complicated than the positive-gear and requires closer adjustment, but on the other hand, it is much more accessible for adjustment, even while in motion, than the positive-gear, which is unapproachable while the engine is running. The oiling of the releasing-gear and the reciprocating and rotating parts of the releasing-gear engine is much easier than that of the positive-gear engine. The problem of oiling the positive-gear engine is one that cannot be considered too carefully, as the success of the gear depends largely upon the perfection of the oiling devices.

850. Compare the throttling and automatic cut-off engines generally, and with respect to economy.

The **simple throttling** engine is the oldest type of engine and is probably the least used at the present time. It is simpler than the automatic cut-off engine, but much less economical, and is usually built for slower speeds. One of the defects of the throttling engine is that, for the purpose of regulation, this machine must have from 5 to 20 pounds more steam pressure on the inlet side of the governor than on the outlet side; consequently, the boiler must generate steam at from 5 to 20 pounds higher pressure than is actually used in the engine; therefore, some waste of heat takes place before the steam arrives in the working cylinder. The automatic cut-off engine adjusts its energy to the resistance by measuring out a supply of steam always at or near the boiler pressure, and sufficient in volume to overcome the resistance; the throttling engine always supplies the same volume, but varies the pressure to suit the resistance to be overcome. The automatic cut-off engine is capable of high ratios of expansion; the throttling engine as usually built is not, ¾ cut-off being the prevailing point.

851. Are there any throttling engines built with comparatively simple valve gears that give a fairly economical steam consumption?

Yes. The **Meyer valve** engine, in which a separate expansion valve on the back of the main valve, worked by a separate eccentric, is used to effect a cut-off from 0 to ¾ stroke. This class of engines is capable of being operated with high ratios of expansion and is quite economical; they are provided with a throttling governor. The point of cut-off is adjustable by hand and is set very close to the average demand, allowing the governor very little range of pressure to adjust the speed of the engine.

852. What determines the use of compound engines?

The cost of fuel and the amount of power required are leading factors in determining the use of compound engines. When the power required is less than 200 horsepower and the steam pressure is limited to 100 pounds gauge, it will hardly pay to put in a compound condensing engine, unless the cost of fuel is very high. If 125 pounds of steam pressure can be carried by the boiler, it will be a paying investment. In the case of a compound non-condensing engine, the boiler pressure should be at least 150 pounds gauge. As the size of the engine increases, it becomes more important to run compound, for the reason that a 1,000-horsepower engine does not cost five times as much as a 200-horsepower engine of similar design and construction. When the price of fuel is low, compounding becomes of less importance and compound non-condensing engines with a variable load when working with steam pressures not above 150 pounds are rarely paying investments.

853. Are triple- and quadruple-expansion engines more economical than compound engines?

Triple-expansion engines have shown an economical advantage over compound engines varying from zero up to 20 per cent. Such engines should not be used with less than 160 pounds steam pressure. Triple-expansion non-condensing engines and quadruple-expansion condensing or non-condensing stationary engines seldom prove a good investment under ordinary conditions. This statement refers to land engines, but not to marine engines, where quadruple engines are sometimes used not only to secure extreme economy in the use of steam, but also to reduce the vibrations of the ship to a minimum.

854. In deciding between the use of a simple and compound engine, what elements, besides first cost and economy of fuel, should be considered?

The **compound** engine is always more complicated and therefore more liable to a breakdown, and requires the carrying of more spare parts. It requires a higher degree of skill to maintain it in economical condition, and requires more expensive boilers, but does not require as large a boiler plant. The question of greater insurance risk and that of facilities for repairs should also be considered in determining the type of engine. The real test in any case is the final influence of the machinery used on the profits of the business.

855. Describe the cylinder arrangements of tandem compound engines and the advantages of such arrangements.

The cylinders are arranged sometimes with the high-pressure cylinder behind and sometimes with the low-pressure cylinder behind. Both arrangements have their advantages. When the low-pressure cylinder is placed behind and the front low-pressure cylinder head is made on an internal flange, the cylinders and pistons are quite accessible. When the high-pressure cylinder is placed behind the low-pressure, the piston rod must be removed through the front low-pressure stuffing-box, and, consequently, can have no projecting collars forged on it to take the thrust of the low-pressure piston. The rod is sometimes fitted with loose steel collars that take the thrust of the low-pressure piston; sometimes the position of the rod that enters the low-pressure cylinder is made rather large in order to form a sufficient shoulder for the low-pressure piston to bear against. When it becomes necessary to forge a collar on the rod to secure a sufficient bearing shoulder for the low-pressure piston, the stuffing-box throat must be bushed; the collar will then pass through the throat when the bushing is removed. Both pistons should have tapered seats on the rod.

856. What are the principal disadvantages of tandem compound engines?

The principal disadvantages are the inaccessibility of the cylinders and pistons for inspection or repair, and the fact that the cylinders are liable to get out of alignment if not properly designed and constructed, which reduces the mechanical efficiency of the machine.

857. How is the loss of alignment of the cylinders of a tandem compound engine obviated to a considerable extent?

The loss of alignment is obviated to a considerable extent by having a heavy cast-iron sole plate extending under both cylinders. The front cylinder is securely bolted to this sole plate, while the rear cylinder is arranged to slide in suitable ways, which constrain it laterally, but allow it to move longitudinally when it expands and contracts. This feature is important in large engines.

858. Compare the cross-compound and tandem engines with regard to spare parts required.

The cross-compound engine has considerably more parts than the tandem, but many of them are exact duplicates, so that the cross-compound engine would probably not require a larger total number of spare parts than the tandem. On account of their smaller size, for equal engine power, the first cost of many of the spare parts for a cross-compound engine would be less than for the tandem engine.

859. Compare the cross-compound and tandem engines with respect to mechanical efficiency.

For equal engine power, the relative mechanical efficiencies of the two types of engines should be in favor of the cross-compound engine. The frictional resistances of pistons and rods should be the same in both, but in the tandem compound they are much more liable to increase in time, due to its greater liability to get out of alignment. The valve-gear resistances should be practically the same in both types, but usually are slightly in favor of the tandem compound. The resistances at the crossheads and crankpins are the same in both types, although there are twice as many parts in contact in the cross-compound engine. The greatest difference in frictional resistances of the two types of engine is at the shaft. For the same steadiness of rotation, both engines working at the same economical ratio of expansion and speed, the tandem engine requires a wheel about 1.6 times heavier than a cross-compound engine. This requires a larger and heavier shaft and bearings and means an increased rubbing velocity of bearing surfaces, and more wear and oil; in this respect the cross-compound engine has a decided advantage over the tandem.

860. Compare the cross-compound and tandem engines with regard to first cost.

For similar service, economy, speed, pressure, and type, the first cost of the tandem engine will average about 9 per cent. lower than the first cost of the cross-compound engine. The cost of the foundation for a tandem engine will be about 20 per cent. less than for the cross-compound engine. Formerly, there was considerable difference in cost between receivers and piping for tandem and cross-compound engines, but as at present constructed, there is no appreciable difference. The prevailing practice at present for equal duty is to give both types of engine a reheating receiver of a volume usually equal to the volume of the low-pressure cylinder; and it is customary to provide for both types of engine about 40 or 50 square feet of tube reheating surface for each cubic foot of steam exhausted by the high-pressure cylinder per stroke.

861. Compare the tandem and cross-compound condensing engines with respect to smoothness of running.

Compression is the main factor tending to secure smoothness in turning over the dead centers. If the vacuum in the low-pressure cylinder is good, the remaining vapor becomes so rarefied that ordinary means will not secure sufficient compression to absorb the inertia of the reciprocating parts at the end of the stroke, the result being a pounding at all journals. To prevent this, extraordinary means must be used, such as providing separate valve gears to drive the exhaust valves independently of the steam valves. In the tandem engine, both pistons being on the same rod, sufficient compression can easily be obtained behind the high-pressure and low-pressure pistons to fully absorb the inertia of the reciprocating parts. This applies particularly to releasing valve-gear engines.

862. What is meant by a duplex engine?

An engine that consists of two simple engines, usually exact duplicates in all parts, operating on one crank-shaft. A duplex engine is similar in arrangement to the cross-compound engine.

863. Why are reversible engines almost invariably duplex?

Reversible engines are almost invariably duplex to facilitate starting the engine at any possible position at which the cranks may happen to be. Locomotive and hoisting engines are familiar examples of this type of engine.

864. Compare the simple and duplex engines with respect to mechanical efficiency and smoothness of running.

The mechanical efficiency of the simple engine of equal power, compared with the duplex, should be a little higher. There will not be much difference in the economical performance of the two types of engine unless the sizes are such as to render the duplex very small in which event the economical efficiency of the duplex engine will suffer a loss. The simple engine of equal power, and if run at the same speed as the duplex engine, to secure the same steadiness of rotation, will require a flywheel about 1.6 times heavier than the duplex, and necessarily a heavier shaft and larger bearings; this reduces the mechanical efficiency of the simple engine. The duplex engine should operate more smoothly than the simple engine because of the more even turning movement at the crank-shaft.

865. What engines may be classed as high-speed and slow-speed machines?

Engines with a releasing-valve gear, usually of the four-valve type, and regulated by a pendulum governor, are classed as slow-speed engines, barring a few exceptions, while positive automatic cut-off engines, regulated by means of a shaft governor, are invariably classed as high-speed engines. Engines regulated by means of a throttling governor are seldom classed as high-speed or slow-speed engines, because they usually run at speeds midway between those of the two first-mentioned classes of machine. In considering the relative merits of high-speed and slow-speed engines, the speed refers to the revolutions per minute, and not to the piston speed, for the reason that the piston speed of modern slow-speed engines often exceeds that of the high-speed engine.

866. Explain the purpose, advantages and disadvantages of high-speed engines.

The **high-speed** engine is being applied in nearly every service, either direct-connected or by belting, but in the electrical field it finds its largest market. Its principal merits are comparative low first cost and small space required; its principal objections are wastefulness of fuel and need of constant attention. There are some high-speed engines on the market that are about equal in economy and other respects to any of the slow-speed engines. There are also some high-speed engines of the enclosed crank-chamber type that, to a great extent, are self-lubricating and demand very little attention, but the majority of high-speed engines are not very economical and must be carefully watched.

867. What forms of valves are principally used on high-speed engines, and what are their relative advantages and disadvantages?

High-speed engines are almost invariably fitted with a balanced valve, which is frequently a piston valve. This type of valve, if used on a horizontal high-speed engine, will soon begin to leak and will get worse with age, notwithstanding the many devices used to adjust the fit of these valves in their liners or casings. The piston valve applied to the vertical engine has given better results, but even here it has not been altogether satisfactory, principally because the system of regulation imposes varying travel on the valve and unequal wear on the internal surface of the casing or liner. Other systems of balancing are by means of pressure-plates or cover-plates; these require very careful design and workmanship, but if properly designed and fitted, they are much superior to the piston valve. The clearance with the latter form of construction is usually much less than with the piston valve, but the clearance is generally large in all of them, and it is due to this fact that the period of compression can be lengthened and the engine be made to operate very smoothly. The Corliss valve has been used on high-speed engines, but the result has not been satisfactory, and in several instances they have been absolute failures.

868. How do high- and low-speed engines compare with regard to closeness of regulation?

The regulation of the high-speed engine is much superior to that of the low-speed engine, even though the latter are fitted with governors equally sensitive. If the high-speed engine is running at 300 revolutions per minute while the slow-speed engine is making 100 revolutions per minute, the high-speed engine may be said to have 600 opportunities to adjust the steam supply while the slow-speed engine has only 200.

869. How is the increased risk of wear and the liability to accident due to the rapid motion of high-speed engines reduced by the builders of such engines?

The increased risk of wear and liability to accident is reduced by selecting higher grades of material, providing liberal wearing surfaces, which are case-hardened or oil-tempered, and using safe and thoroughly tested constructions, involving massive and well-distributed framing.

870. In high-speed engines, what provision is made to collect the excess oil to prevent wastes?

The wastes of oil in high-speed engines are provided against to a great extent by providing splashers, oil guards, and drip pans, and in some designs by completely enclosing the running parts in oil casings. In some systems provisions are made for draining and collecting all oil in a separate chamber, where it is carefully strained or filtered and automatically returned to the bearings. In this system, which is known as **the oil return system,** liberal streams of oil are kept running upon the bearing surfaces.

871. How do high- and slow-speed engines compare with regard to accessibility?

From the compact, rigid nature of the design of high-speed engines, they are not as accessible as the slow-running machine, but in many cases they are not particularly difficult of access.

872. Why are the flywheels for high-speed engines made much lighter than those for slow-speed engines?

Owing to the velocity of the high-speed engines, the wheels can be made much lighter and still obtain the same degree of steadiness as in the slow-running engine. This relieves the bearings of much dead weight and allows the shaft to be made smaller and makes the velocity of its rubbing surfaces much less.

873. Explain one manner in which the fast rotative speed of high-speed engines contributes to the economy in steam consumption.

The fast rotative speed allows little time for initial condensation of each charge of steam and for the changes in temperature preceding each charge, which results in a saving of steam.

874. **Give some of the advantages of high-speed engines for direct-connected work.**

There is a direct saving due to the omission of transmission machinery, as jack-shafts, belts, bearings and their foundations, and the continuing expense resulting from their attendance, lubrication, and repair.

875. **Why do high-speed engines demand a larger boiler plant?**

Owing to their greater steam consumption, high-speed engines demand a 20 per cent. larger boiler plant.

876. **What is the common range of power of high-speed engines?**

The common range of power is from 60 to 200 horsepower, but they are occasionally built in units as large as 800 to 1000 horsepower.

877. **Are high-speed engines built compound and triple-expansion?**

Yes. High-speed engines are as commonly built compound and triple-expansion as are slow-speed engines, and they are more frequently built compound non-condensing than are slow-speed engines. The compounds are arranged both cross and tandem.

878. **In the slow-speed engine, what means are taken to secure extreme economy of steam and high mechanical efficiency?**

The valves are usually so placed as to reduce the clearance volume and clearance surface to a minimum; great care is exercised to free the cylinders of water; steam jacketing of heads and cylinders is common. The polishing of the internal faces of heads and pistons in order to reduce the activity of the metal in receiving and imparting heat to the working steam, and thus reducing initial condensation, is sometimes resorted to. Elaborate valve gears to give refinement of steam distribution are possible with the slow-speed engine.

879. How do the high- and slow-speed engines compare with regard to first cost?

The slow-speed engine is much the larger, heavier, and more expensive machine, and may cost 1.3 times as much as the high-speed engine of equal power. The foundations are also more expensive, but the boiler capacity need not be so large.

880. How do the high- and slow-speed engines compare with regard to economical performance?

Assuming the two engines to be in fairly good condition, and of the simple non-condensing type, the economical performance should be about 30 pounds of steam per horsepower per hour for the high-speed and 24 pounds of steam per horsepower per hour for the slow-speed, bearing in mind, however, that the slow-speed engine will for a long time maintain its economical performance, while the high-speed engine will generally lose in efficiency.

881. In the generation of electricity by steam power with direct-connected engines, why is the high-speed engine used for units of, say 200 to 300 horsepower, while for larger units the slow-speed engine is used?

The slower the rotative speed of direct-connected engines the larger must be the diameter of the armature or revolving field of the electrical generator, which increases the first cost of the unit. It is for that reason that the high-speed engines are used; but after passing a power of 200 or 300 horsepower, the item of economy becomes of such magnitude that the more economical and more expensive slow-speed engines are used. Furthermore, large generating units are necessarily larger in rotor-diameter than smaller units.

882. How do the high- and slow-speed engines compare with regard to workmanship and the attention they require?

Slow-speed engines, besides being more economical, do not require such close attention as the high-speed engines. In many instances the slow-speed engine will give fair warning of approaching danger that will be developed too quickly to control in the high-speed engine. The slow-speed engine is more accessible and more readily adjusted. The workmanship need not be so exacting for equal results, and the life and service of the engine are greater. The regulation of the slow-speed engine is not equal to that of the high-speed engine, and they require much heavier wheels for the same degree of steadiness.

883. What elements should determine the selection of an engine for a specified service?

The kind of service, the location, first cost, cost of fuel delivered at the boilers, steam pressure available, the duration of service, the facilities for repairs, the kind of labor available, all the existing conditions, probable extensions, whether the engine shall be condensing or non-condensing, and whether one large engine shall be used or whether the power shall be divided into several smaller units. The problem of selecting an engine for a specified service is one demanding skill, experience and forethought.

884. What type of engine should be selected when the engine is required to run continuously with a uniform load?

In this case the cost of fuel should be the first question to be considered. If the cost of fuel is high, the steam should be worked expansively and in a high-grade engine. Whether this be high-speed or slow-speed depends on the particular work the machine is to do. If the engine is direct-connected to an electric generator of not over 200 horsepower demand and the steam pressure is 125 pounds, while water is available for condensing purposes, a compound condensing high-speed engine having separate steam and exhaust valves and a governor controlling only the admission valve should be used. If the power demanded is large, the slow-speed high-grade engine should be the choice and the cost of fuel should dictate in great measure the steam pressure, the ratio of expansion, and the details in all directions, to the end of reducing total expenditures. If no water be available for condensing purposes the compound non-condensing engine will prove a good investment. It should have at least 140 pounds of steam pressure, and should not be too large for its work. As far as economy is concerned, it is better to have this type of engine too small rather than too large for its work.

885. What type of engine should be selected when the engine is required to run continuously with a variable load?

For continuous running with variable load the compound condensing engine is most suitable, as it works over a wide range of expansion without materially affecting its economical efficiency. The simple condensing engine is well suited for the purpose. If condensing water is not available and if the cost of fuel or demand for power is not sufficient to warrant the use of a cooling tower for condensing water, then the slow-speed non-condensing engine working with a steam pressure of 100 pounds should be the choice.

886. What type of engine should be selected when the engine is required to run continuously with a uniform but increasing load?

For continuous running with a uniform load, which is expected to be increased through extension of business, the simple non-condensing engine should be selected, and arrangements should be made to make it into a duplex engine, a condensing engine, or a compound condensing engine, as demands are made for increase of power. It would not be economical to provide for converting the machine into a compound non-condensing engine on account of the high pressure required successfully to operate this type of engine. If no condensing water is available, the increased power could be most easily and inexpensively provided by making the engine a duplex.

887. What type of engine should be selected for intermittent running?

For intermittent running there is much dispute among engineers as to the best type of engine. The problem of choosing an engine for intermittent work demands the study of local conditions, in which the cost of fuel is probably the most important determining condition. If the cost of fuel is high, and the power demanded is large, the high-grade multiple expansion engine should be a paying investment even though the extra expense of providing a cooling tower for the condensing water be added. If the power required is small, the high-grade engine is very seldom used, even though the cost of fuel be large. For reversing rolling-mill service, the simplest and strongest type of engine is used. For industries such as the beet, cane sugar, wood pulp, etc., where there is usually considerable refuse, having more or less value as a combustible, the simplest, strongest, and cheapest constructed type of engine is chosen.

888. What influence has the location on the selection of an engine?

The location has an all-determining influence on fuel cost, and an engine located in the coal-mining districts may be selected wholly with reference to low first cost; while in districts where the price of fuel is high, the high-grade engine must be selected in order to secure small consumption of fuel. The cost of transportation must also be considered in connection with the location. Where the cost of transportation is high, the smaller high-grade engines are selected instead of large engines working at high ratios of expansion. But even here the item of fuel cost should be considered. Where the fuel, and perhaps even the water supply, must be transported in the same manner as the engine parts, the high-grade engines working expansively are often chosen. Existing conditions at any given location, such as steam pressure available, speed desired, feasible method of coupling, and the availability of condensing and feed water, should also be considered in connection with the selection of an engine.

889. What influence has the first cost on the selection of an engine?

When the outlay for fuel is small compared with the running expenses, due to a small demand for power in the particular industry, low first cost may prevail; but, if the power requirements are large, even though the price of fuel is moderate, the engine most economical in the use of steam, although high in first cost, should be selected.

890. What influence has the fuel cost on the selection of an engine?

When fuel is cheap and, as in some cases, must be burned to dispose of it, a very simple engine and one low in first cost should be selected. In such cases the engine should be of such design as to require as little attention as possible, because where cost of fuel is of little or no consequence, the whole steam plant is liable to be neglected, particularly the engine. When the cost of fuel is high, the highest-grade engines should be selected, and every known means for saving fuel should be employed. The extent to which the various means and devices for securing small consumption of fuel should be used at the engine would naturally depend on the price of the fuel.

891. What influence has the steam pressure available on the selection of an engine?

The steam pressure available is generally the element that determines whether an engine shall be single-cylinder or multiple-expansion. Generally the steam pressure should be at least 100 pounds gauge for effective compounding with a condenser, while 135 pounds should be available for compound non-condensing engines and at least 160 pounds for triple-expansion condensing engines.

892. What influence has the duration of service on the selection of an engine?

If an engine is to be installed for the purpose of doing useful work for a long period of time, the high-grade types should be selected. But, if an engine is to be installed for temporary service, or is to be sent to a distant locality, as for construction work, and the expenses of transportation are such as not to warrant its return, an engine of low first cost, but strong, simple and well built, should be selected.

893. What influence have the facilities for repairs on the selection of an engine?

If facilities for repairs are not at hand, in instances of small and even moderate-size plants, the simplest and strongest types of steam engines should be selected. This, however, does not obtain in the case of large installations, where the cost of fuel is high or even moderate. The difficulty can be met by providing spare parts, or relay engines. If the facilities for repairs are not at hand, carrying spare parts is advisable, as accidents and defects are possible with the most carefully constructed engines.

894. What influence has the kind of labor obtainable on the selection of an engine?

High-grade economical engines generally require intelligence and skill to maintain them in that condition. Therefore, where skilled labor is not obtainable, the simplest and strongest types of engines should be the choice.

895. What determines the use of condensing or non-condensing engines?

The question whether to run condensing or not usually depends for its answer on the natural supply of cooling water available, and frequently the supply of cooling water determines the location of the steam plant. There is a decided gain by the use of a condenser, not only in fuel, but in first cost, as a condensing engine may be made, on the average, 20 per cent. smaller and almost 20 per cent. cheaper than one not provided with a condenser. The cost of the air pump and condenser must also be considered. If directly connected, the air pump being driven by the main engine, this cost should be about 10 per cent. of the cost of the engine for average sizes, and the air pump and condenser should require about 2 per cent. of the power of the engine to drive it. If an independent condenser is used, which for many reasons is the most desirable arrangement, it should cost about 15 per cent. of the cost of the engine, in the case of slow-running high-grade engines. High-speed and inferior engines require condensers larger in proportion, owing to the larger amount of steam used. For large plants, where abundant natural water is not to be had, the cooling tower may be used to extract the heat from the injection water and to permit of using it repeatedly.

896. Give some of the advantages gained by installing a number of small engines instead of one large one in a manufacturing plant.

In many industries, departments require the use of power for only a short time or at intermittent periods during the day, and frequently demand widely varying speeds for best effects; they are also frequently required to be operated overtime or all night. Long-distance transmission of power is also involved. In such cases it will often be found that subdivided power will give the best results.

FOUNDATIONS AND ERECTION OF ENGINES

897. What is the purpose of the engine foundation?

The purpose of the engine foundation is not only to support rigidly the engine, but also to absorb the jars and shocks due to its reciprocating motion, because if these are not absorbed, they will result in injury to the engine in question and also to foundations, walls, and structures of any kind resting on the adjacent soil.

898. What area should be allowed a foundation to prevent settling?

The **area** to be allowed a foundation depends upon the supporting power of the soil on which the foundation is to rest. Accepted figures for the supporting power of various soils range from 1 ton per square foot for soft clay to 5 tons per square foot for compact sand bottom, while 200 tons per square foot is given as the supporting power of hard rock in natural beds.

899. What should be the depth of an engine foundation?

The **depth** of a foundation will vary with conditions, but it is rarely less than 4½ feet for small engines and rarely more than 22 feet for the largest engines. Different types of engines require somewhat different designs for their foundations; experience has been and is the only teacher in this subject.

900. How are the vibrations of engines, set up by the starting and stopping of the reciprocating parts, absorbed?

In high-speed engines careful counterbalancing is used to balance the reciprocating parts in the horizontal direction. This balancing in horizontal engines tends to prevent the engine from sliding lengthwise upon its foundation, while in the vertical engine the revolving counterbalance tends to slide the engine upon its foundation in a horizontal plane, and the foundation in either case must be of sufficient mass to absorb the vertical and horizontal forces, since engine framings and sub bases rarely have sufficient mass to absorb vibrations. When engines are on the upper floors of buildings, the scheme of suspending a very heavy mass underneath the floor, but rigidly bolted through to the engine base, has proven effective in preventing vibrations. In placing engines upon solid rock some elastic medium, such as wood, hair felt and cork, is used between the machine and the rock to prevent vibration of the engine from being transmitted to adjacent property.

901. Why should vertical engines have deeper foundations than horizontal engines?

Horizontal engines usually occupy so much space in a horizontal plane that the supporting power of the soil will be very much above the load even if the foundation is made as small as possible. Vertical engines, owing to the small horizontal space required, should have deeper foundations than horizontal engines, and to secure sufficient bearing area, the sides may be battened to any desired extent. Bearing surfaces for vertical engines should be carefully calculated with reference to the nature of the supporting soil, including the weight of the foundation itself as well as that of the engine which it supports.

902. Of what materials are engine foundations usually made?

Brick is the most common material; dressed stone laid in cement mortar is sometimes used; concrete is now generally used for engine foundations.

903. Explain how the various materials should be used in making engine foundations.

When brick is used, it should be first quality hard brick laid in Portland cement mortar. Stone foundations should also be laid in cement mortar, because lime mortars have a tendency to disintegrate under vibration, and are therefore not suitable for engine foundations. Concrete foundations are constructed by first providing a level and suitable footing upon which a casing of timber, embracing the outlines of the foundation, is built. This is open at the top and bottom. The foundation bolts are suspended in pipes, or wood boxes, leaving a space of at least 2 inches all around the bolt. Successive layers of cement concrete are thrown in and well rammed until the desired height is reached.

904. In what cases are foundation footings required and how are they constructed?

Foundation footings are required where it is necessary to go many feet deep to find a sufficiently hard bottom to support the load. This is accomplished most commonly by piling, which consists of driving long sticks or timbers down to a hard bottom, placing them 2½ to 4 feet apart from center to center. A timber grating or grillage is fastened to the tops of the piles and a layer of concrete is deposited. The space between the piles is frequently filled with rubble, clay, or concrete, and upon this footing the foundation proper is built. A pile 7 inches in diameter will bear about 12 tons. A pile can support a load of 25 tons when it refuses to move more than ⅜ inch under thirty blows of a hammer weighing 1,200 pounds and falling 4 feet.

905. When rock is struck at high level, how are footings constructed to prevent vibrations?

A layer of 2 to 3 feet of sand constrained laterally by a casing to prevent displacement has proved quite effective. The sand is also filled in around the sides of the foundation block. A heavy layer of asphalt is also effective in breaking up engine vibrations before they reach the transmitting rock upon which the foundation is bult.

906. Do all engine foundations require capstones?

Brick and dressed stone foundations usually require capstones to make a good job. Concrete foundations usually require no capstone. Capstones are usually granite and vary in thickness from 8 to 24 inches.

907. Describe the sole plate sometimes used instead of capstones.

It is a cast-iron plate about ⅞ or 1 inch thick, with an upturned ledge around the top to keep oil from the foundation and with sufficient ribs below to give stiffness to the plate, and is provided with raised planed facings to match the engine parts. Sole plates are not more expensive than good capstones and constitute a superior job. Every precaution should be taken to keep oil from reaching the foundations, as it will injure the cement.

908. What is the object of setting the capstone for the outboard bearing of an engine lower than the plan figures call for?

If the capstone is set low the bearing can be shimmed up with wrought-iron strips or plates, but if it is set a little too high it is a difficult matter to do anything with it except to chip off the top or take it up and reset it.

909. Describe foundation bolts and washers for engines, and how they are installed.

Foundation bolts are always made of wrought-iron, and should be of good quality, as Burden's best-best, Catasauqua, or some equivalent brand. Foundation bolts are usually made in a length nearly the full depth of the foundation, and in important work they are made **upset,** that is, the threaded portion is made enough larger in diameter so that the bottom of the thread is still a little larger than the body of the bolt. By this means stretch due to the pull on the bolt is distributed over the long body and not localized at the threads. Foundation bolts vary in diameter from 7/8 inch in small engines to 4 inches in the largest types of land engine. Foundation washers are commonly made of cast-iron, but for small engines wrought-iron plates from 3/8 to 3/4 inch thick are used. In locations where it is not possible to provide pockets for access to the foundation washers, a style of foundation wire is provided which makes it possible to adjust the bolts to any desired height, or even to remove them and replace them at will. The tops of some foundation bolts are tapped for an eyebolt to facilitate lifting or lowering the bolt in place. In large work it is quite important to have the foundation bolts removable, for if they extend through high framing or high bosses, it is necessary to lift the castings over the top of the bolts, which adds much to the cost of erection. With many engineers it is the custom to build foundations with pockets, omitting the holes for the bolts entirely. When the capstones are leveled and grouted, they lay off the holes from the castings and drill holes for the bolts with a diamond drill. Sometimes the engine is erected, lined up, and grouted, and then the holes for the foundation bolts are drilled in place.

910. Describe how foundation templets are constructed and used.

Foundation templets are used for the purpose of locating the bolts, bringing them to the proper height, and holding them in position while the masonry is being built. They are constructed of wood with supporting blocks of varying height to suit the height of the engine bosses. The center line of the engine is carefully marked on the templet with correct relation to the bolts, and at right angles to it is marked the center line of the crank-shaft. Suitable marks and dowels to facilitate putting it together, if of such dimensions that it is necessary to ship it in sections, are also provided. The foundation bolts should not be allowed to hang on the templet, but should rest on stone or bricks. The bolts, if they have no adjustment, should be set originally from 1 to 2 inches higher than required, as the gradually increasing weight of the foundation will sink the soil upon which it was started, and hence the bolts may not project through the engine casing unless this precaution be taken. Bolts when used in pockets, or with box washers, should be pointed to facilitate entering the nut. Templets for outboard bearings of compound or triple-expansion engines are usually not connected, the relative locating being done from the foundation drawing. This work is usually done by the engine contractor.

911. How is a foundation templet supported?

Generally it should be supported outside of the foundation, but there is no real objection to building the supporting posts into the mass and sawing them off when the foundation has reached about 18 inches from the top. It is best, however, to leave the supporting of the templet to the erecting engineer.

912. Describe a method of setting a templet.

The first and most important thing to do is to have the templet exact; particularly, the crank-shaft center line must be square with the center line of the engine. This can be tested by measuring off from the intersection of the two lines 6 feet on the shaft center line and 8 feet on the engine center line and adjusting the lines with their intersection as an axis until the hypothenuse of the triangle measures exactly 10 feet. Then having given the templet the correct relative position and the correct levels, the only remaining thing to do is to set the center line of the crank-shaft parallel to the line shaft or its established line. This can be done by plumbing down from or to the line shaft and measuring at both ends of the crank-shaft center line from that line to the plumb-lines. Having properly set the templet, the bolts are passed down through the holes and the washers and nuts put into place. Each bolt must rest on a large stone slab. Old pipe or wooden boxes should be put around the bolts to allow considerable lateral adjustment of the bolts.

913. Describe how an engine is placed on the foundation.

When the foundation is built up to within 2 feet of the top, the templet is removed and the top of the foundation built and carefully leveled by means of sensitive levels and straightedges. If the engine is large and the wheel is in halves, one-half the wheel should be placed in the wheel pit first; then the framing, outboard bearing, and shaft may be placed, and finally the cylinders and valve gears. The engine is leveled in a plane parallel with the center line of the shaft and cylinder by means of sensitive spirit levels and all parts resting on the foundation are wedged and shimmed up. The bolts are tightened down moderately and the space between the bedplate and foundation, which will vary from ¼ to ⅝ inch, is filled with **grouting.**

914. Explain how grouting may be prepared and applied.

Grouting may be made of 2 parts of sal ammoniac, 1 part of sulphur, 5 parts of cement, and 4 parts of iron borings mixed with enough water to make a heavy paste (rust joint). Sometimes melted sulphur alone is used, but one of the very best groutings and the most easily applied is pure Portland cement. The rust joint must be driven in, while the sulphur and cement will flow in, suitable dams being constructed to constrain it to its proper place. Bolt holes should be filled with liquid grouting. Some builders who use box bedplates fill the entire bedplate with concrete to give it solidity and to reduce the tendency to magnify knocks into pounds.

915. Explain the setting and aligning of the outboard bearing.

The setting and the aligning of the outboard bearing should be carried along with the progress of the other work, but its final adjustment is important and should be done last, by the aid of lines representing the center lines of the cylinder and crank-shaft. All outboard bearings should be provided with a sole plate and means for lateral adjustment either by screws or wedges, while some are provided with means for vertical adjustment.

STEAM TURBINES

916. What is a steam turbine and what types have attained commercial value?

The steam turbine is a steam engine working on an entirely different principle from that of the ordinary steam engine. Instead of making use of the **pressure** of steam, they utilize the kinetic energy contained in a mass of steam moving with a very high **velocity,** jets of steam impinging against the blades or vanes of a wheel fitted inside of a suitable casing and thus rotating the wheel at a high speed. This kind of engine, from its similarity to the water turbine, is called **a steam turbine.** Many steam turbines are in use, modern designs giving an economy about equal to that of the best reciprocating engine. The **Parsons** turbine dates from 1884. It differs from the **De Laval** machine mainly in that the steam velocity increases **gradually** as the steam passes through a large number of successive rows of fixed and moving blades, while in the De Laval machine the steam velocity is produced suddenly in a nozzle and decreases rapidly as the steam traverses one or two rows of blades. **Curtis** turbine was placed on the market in 1903 by the General Electric Company. The De Laval, Parsons, and Curtis turbines are the types best known in units of large size.

917. What are the advantages of the steam turbine?

The general advantages of the steam turbine are no leakage from wear, small friction loss, high efficiency with variable loads, no moving parts under high pressure, close speed regulation, simplicity of construction, perfect balance, small foundations, small space occupied, ease of erection, automatic oiling, less danger from condensation, and long life. The special advantages of turbines of the Westinghouse-Parsons and the Curtis types are increased speed, greater economy of steam, reduced weight, reduced space occupied by machinery, reduced cost of attendance, reduced repair bills, and reduced vibration.

918. Give a general description of the De Laval steam turbine.

The turbine wheel is mounted on a flexible shaft running in three bearings, one of which is a so-called **flexible bearing.** Two bearings are rigid, while the third is fitted in such a manner that it can accommodate itself to any bending of the shaft. The flexible bearing is really not a bearing at all, since it does not support the shaft, but merely closes the opening where the shaft passes out of the casing. In reality it is a stuffing-box so mounted as to accommodate itself to any bending of the shaft, and preventing the entrance of air to the casing when running condensing, and the escape of steam when running non-condensing. The turbine wheel runs within the casing that carries the nozzles. The turbine wheel has such a high rotative speed that very little machinery in use can be coupled directly to the shaft and, therefore, gearing is resorted to. The shaft carries two pinions meshing with two gear-wheels, which generally have 10 times as many teeth as the pinions, thus reducing the speed to $\frac{1}{10}$ the speed of the turbine wheel. One set of these gears has right-handed helical teeth while the other set has left-handed helical teeth. As a result of this there is practically no tendency for the shaft to move endwise. The gears are enclosed in a case partially filled with oil. The machine to be driven by the turbine is connected to the shaft, either by being coupled to it directly or by being belted to a pulley keyed to the shaft. The shaft carries on one end a centrifugal governor that operates a double-seated throttle valve by means of a bell-crank lever. The steam and exhaust pipes are screwed into flanges in the casing, the exhaust pipe leading either to the atmosphere or to the condenser.

919. Describe the construction and operation of the governor used in connection with the De Laval turbine.

It consists of a frame fastened to the end of the shaft by a taper shank and carrying two weights hung on knife-edge bearings. These weights fly outward under the action of the centrifugal force until the resistance of the two springs is equal to the centrifugal force. In moving outward, the weights force the governor stem to the right, which in turn rotates the bell-crank and causes the governor valve operated by it to assume a position corresponding to the speed of the governor. When the speed falls, the governor weights move inward, and the governor valve is opened farther by them, thus admitting more steam. When the speed rises, the centrifugal force increases and the governor weights move farther outward; this closes the governor valve farther and thus reduces the amount of steam admitted. The speed at which the turbine will run can be varied somewhat by changing the tension of the governor springs, increasing the tension to make the turbine run faster and decreasing it to make the turbine run slower.

920. Explain the purpose and operation of the vacuum valve used in connection with condensing De Laval turbines.

When the turbine is running condensing, it has been found that the governor valve alone will not give sufficiently close regulation during a sudden and large decrease of load. To assist the governor valve in controlling the speed under these conditions the **vacuum valve** is employed. Its function is to admit air to the space in which the wheel revolves and thus to destroy or impair the vacuum; the resistance of the air then checks the speed of the wheel. The vacuum valve is operated by the governor as follows: when the speed under a sudden decrease of load becomes excessive, the governor first closes the governor valve entirely. The governor weights continue to move outward after this and force the governor stem farther to the right, compressing the spring in doing so. An adjustable stud then strikes the end of the vacuum valve and forces it inward, thus admitting air. When the speed has been sufficiently reduced, the governor weights move inward and consequently the stud moves away from the vacuum valve, allowing it to close. As the weights continue to move inward, they open the governor valve again and admit steam to the turbine once more.

921. What is the purpose of the flexible shaft employed in the De Laval steam turbine?

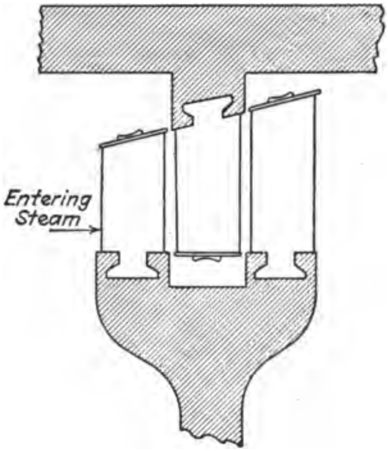
The vibrations of the shaft and the wheel at high speeds are very much reduced by an extremely careful balancing of the revolving parts, and by making the shaft itself slender and therefore flexible. With rigid shafts running in rigid bearings, the most careful balancing failed to prevent excessive vibration at very high speeds, as the centrifugal force generated by the absence of absolute balance is very large.

922. Describe the De Laval nozzle and its object.

The De Laval nozzle is the means by which steam is used expansively in the De Laval turbine. It consists of a tube with a contracted opening, or **throat,** near the inlet end. The steam passage in the nozzle diverges from the throat to the outlet end. The inlet ends of the nozzle are contained within a ring-shaped passage, concentric with the shaft, to which the live steam is admitted. A valve regulates the amount of steam entering each nozzle, and is also used for cutting one or more nozzles out of service when the turbine is not to be worked under a full load. By discharging the steam through a nozzle with diverging sides an increase of velocity at the discharge end is obtained, the steam in passing through the nozzle expanding down to a low pressure. The object of the De Laval nozzle is to impart a high velocity to the steam, thus giving a great kinetic energy.

923. Describe the Parsons steam turbine and its operation.

In its essential features, the Parsons turbine consists of a turbine shaft, carrying a large number of sets of moving blades, and rotating in suitable bearings within a casing. Steam at boiler pressure enters a ring-shaped passage, whence it passes to the first set of moving blades, which are so shaped that some of the energy of the steam is absorbed, producing motion, while the steam velocity increases and the steam pressure decreases. After passing the first set of moving blades, the steam flows through a set of stationary blades, projecting inward from the casing. Here its pressure is further decreased and its velocity further increased. It then strikes a second set of moving blades, acting as before. A combined set of fixed and moving blades constitutes a **stage.** There may be 60 or more stages, in each of which the steam imparts energy to the moving blades while increasing in velocity and decreasing in pressure. The steam finally passes into a chamber, and thence either to the atmosphere or to a condenser. In order to counteract the end thrust of the steam against the moving blades, balance pistons are fitted on the shaft. Each piston has an area equal to that of the moving blades of the corresponding set of wheels, and as the steam pressure acts against these pistons in a direction opposite to that in which it acts against the blades, the end thrust is balanced. An adjustable bearing similar to a thrust block confines the turbine shaft longitudinally, and at the same time resists any end thrust that may not be balanced by the balance pistons. This type of turbine, as built in this country, is known as the Westinghouse-Parsons turbine. A governor regulates the speed of the turbine. Live steam can be admitted to the middle of the turbine by a by-pass valve for the purpose of increasing the power of the turbine. This, however, causes a reduction in economy. The bearings are flexible and permit the shaft and wheels to revolve about their axis of gravity. All bearings are lubricated by oil under pressure which flows back by gravity to a reservoir, from whence a pump forces it back into the supply



Fixed and Moving Brackets in a Turbine.

reservoir, from where it passes once more to all bearings. Many Westinghouse-Parsons turbines embody a De Laval wheel with nozzles as a preliminary stage. This decreases bulk and cost.

924. **Explain the difference in the manner in which expansion of steam is obtained in the De Laval and the Westinghouse-Parsons turbines.**

In the De Laval turbine the expansion takes place in the nozzle and the steam strikes the wheel at a very low pressure; in the Westinghouse-Parsons turbine expansion takes place gradually as the steam passes from one set of blades to the next. Steam at full boiler pressure impinges on the first set, the pressure decreasing and the velocity increasing as the steam passes from stage to stage.

925. **Explain why the De Laval steam turbine has to be "geared down" for most work, while the Westinghouse-Parsons motor can be connected directly to many machines.**

In the De Laval turbine, in order to get maximum efficiency, the velocity of the wheel must be about 47 per cent. of the velocity of the steam, and as this latter velocity is very high, about 4,000 feet per second, the turbine wheel must have a very high rotative speed and the motor requires to be geared down for most work. In the Westinghouse-Parsons turbine the velocity is produced gradually, and consequently the speed of wheels is comparatively low. This allows the motor to be connected directly to many machines.

926. **Explain the means used for preventing vibration, and the construction of the flexible bearings in the Westinghouse-Parsons steam turbine.**

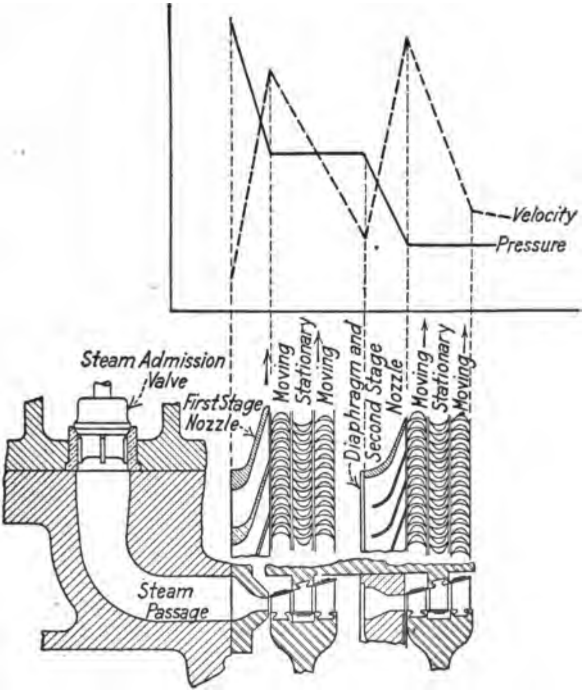
The means used for preventing vibration are a careful balancing of the revolving parts and a construction permitting a lateral accommodation of the bearings. In this type of turbine the shaft is made just as rigid as possible. The construction of the flexible bearings is as follows: The gun-metal sleeve forming the bearing proper is prevented from rotating by means of a dowel. This sleeve is surrounded by three loosely fitting tubes. The space between the tubes themselves and the sleeve is filled with oil, which is supplied under pressure. Since oil is a yielding medium, the sleeve can move laterally to accommodate itself to a displacement of the geometrical axis of the shaft.

927. Describe the governor of the Westinghouse-Parsons steam turbine and its operation.

The governor is a spring-loaded fly-ball governor. By adjusting the tension of the spring loading it, the speed of the turbine can be varied within small limits. The governor valve controlling the admission of steam to the turbine is not attached directly to the governor, but is operated by steam admitted to its power cylinder and exhausted therefrom by a pilot valve controlled by the governor. In operation steam at boiler pressure leaks past the stem and raises the piston, thereby opening the governor valve. Steam is exhausted from the under side of the piston by means of the pilot valve, thereby lowering the pressure below the piston and thus permitting a spring to close the governor valve. The pilot valve is given a to-and-fro motion while the turbine is running, by means of an eccentric on the shaft driving the governor. With each revolution of the shaft when it is driving the governor, the pilot valve is opened and the steam is exhausted from the under side of the piston, which moves downward and causes the steam-admission valve to close, thus completely closing the steam inlet. After a certain interval, the pilot valve closes the exhaust port from the under side of the piston, and the accumulation of pressure opens the admission valve again, admitting steam once more to the turbine. This alternate closing and opening of the admission valve (**puff governing**) occurs about 150 times per minute. Thus the steam is admitted in puffs, as it were. The volume of steam admitted at each opening of the governor valve varies directly as the length of time the valve remains open. The object of the governor is to regulate this length of time, which is accomplished by causing the pilot valve to make its strokes in a higher or lower position, according to which way the speed varies, thus changing the length of time the port leading below the piston remains open. When the speed of the turbine increases, the pilot valve is lifted and makes its stroke in a higher position. In consequence of this, the port leading below the piston remains open for a greater length of time than before, with the result that the spring is permitted to hold the steam-admission valve closed for a longer time. The result of this decrease in the volume of steam admitted to the turbine is a reduction of its speed down to the normal speed. When the speed drops below normal speed, the pilot valve drops to a lower position, thus reducing the time during which steam is exhausted from below the piston, and consequently increasing the time the steam-admission valve remains open. The result is that more steam is admitted at each opening of the valve, which continues until the speed has increased to the normal speed. The object of making the admission valve act intermittently is to admit the steam to the turbine at full boiler pressure irrespective of any variation in load. With a full load, the puffs of steam admitted will be almost continuous.

928. Describe the Curtis turbine and its operation.

In the Curtis turbine the shaft is sometimes vertical, in which case the wheels carrying the moving blades revolve in horizontal planes. The vertical shaft is supported sidewise by bearings and in a vertical direction by a step bearing. The shaft carries a number of horizontal wheels, in some cases 2, and 3 or 4 in other cases. These wheels at their circumference each carry two steel rings in which two rows of moving blades are formed by cutting from the solid metal. Stationary guide blades are placed between each two rings of moving blades. The stationary blade rings are supported by the casing. There is a set of nozzles for each moving wheel. The steam is gradually expanded down by successive expansions in the respective sets. Governing is affected by valves placed in the passages leading to each expansion nozzle, these valves being operated by a governor. The exhaust steam passes from the exhaust chamber to the condenser; in some designs the condenser is placed directly in the base. A Curtis turbine having two wheels is called a two-stage (pressure stage) turbine; if it has three wheels, it is spoken of as a three-stage turbine, and so on. Oil under pressure is forced by a pump into the step bearing, so that while running the shaft is supported on a film of oil. None of the oil used for lubrication mingles with the steam, which makes the condensed steam at once suitable for boiler feeding. The governor itself operates electromagnets, which in turn shut off successive nozzles, by closing their valves whenever the speed exceeds the desired limit. One of the nozzles has its controlling valve so arranged that the flow of steam through it can be throttled to any extent permitted by the construction. The other controlling valves are either entirely opened or entirely closed by the governing mechanism. The steam is first expanded in the expansion nozzles, having its velocity of flow increased thereby; the kinetic energy of the steam is then abstracted by the two following rows of moving blades. A second expansion



Arrangement of Nozzles and Buckets in a Two-Stage Curtis Turbine.

follows in a second set of nozzles, producing velocity which is utilized in the blades of a second wheel. A third or even a fourth and fifth stage may follow. A comparatively low speed of rotation is secured by making the wheels carrying the movable blades large in diameter. Curtis turbines are now almost invariably built with the shaft horizontal.

929. State the fundamental difference in the operation of the common reciprocating-piston steam engine and of the steam turbine.

The chief difference is that, while in the common reciprocating-piston steam engine the steam does work by reason of its pressure overcoming resistance, in the steam turbine the steam does work by yielding its kinetic energy.

930. Compare the steam turbines and reciprocating engine with respect to the losses of heat.

One of the greatest losses of heat in the reciprocating engine is due to the steam's entering passages the walls of which have been cooled by contact with steam of much lower temperature. The weight of steam that is condensed and passed through a reciprocating engine without doing useful work may amount to about 25 per cent. of the total steam consumption of the engine. In the steam turbine, this loss is entirely eliminated. The walls of the steam passages soon attain a temperature equal to the temperature of the passing steam and, as a result of this there is no transfer of heat between the steam and surrounding metal.

931. Compare the steam turbine and reciprocating engine with respect to losses of energy.

A loss of energy to which the turbine is subject and that has no counterpart in the reciprocating engine may be caused by moisture in the steam. A drop of water falls on the wheel and is given a velocity equal to that of the blades. Centrifugal force causes it to fly off against the casing, where its kinetic energy is scattered. Falling back on the wheel it goes through the same cycle of operations again and continues to abstract energy from the revolving blades. Dr. R. H. Thurston, experimenting with a 10-inch De Laval turbine running at 20,000 revolutions per minute, estimated the loss from this source to be 1 horsepower for every 275 drops of water, each having a diameter of $\frac{1}{10}$ inch. Another loss due to moisture in the steam is the retardation of the wheel caused by a thread-like stream of water between the revolving disk and the sides of the casing. Dr. Thurston, experimenting with the same turbine, estimated the loss due to a thread of water $\frac{1}{1000}$ inch in width between the casing and the wheel to be $1\frac{1}{2}$ horsepower.

932. How can the loss of energy in a steam turbine, due to moisture in the steam, be remedied?

The obvious remedy for loss due to moisture is the use of superheated steam, which is possible, because the turbine has no rubbing surfaces on which lubrication is made difficult by steam of a high temperature, as in the reciprocating engine. Experiments with a De Laval turbine show a gain of 1 per cent. in efficiency for every 30° of superheat. Other experiments with other turbines show a gain up to 20 per cent. in economy with 60° superheat.

933. Compare the steam turbine and reciprocating engine with respect to efficiency, measured by the steam consumption per horsepower, and the use of oil.

The efficiency of the steam turbine measured by the steam consumption per horsepower equals and in some cases excels that of the best types of reciprocating engines. The amount of oil required is much less than with the more common type of engine, as there are comparatively few bearings to oil, and no cylinder oil is required. The absence of cylinder oil is quite a decided advantage when exhaust is condensed and returned to the boiler, because the water will be entirely free from oil.

934. Compare the steam turbine and reciprocating engine with respect to horsepower.

The horsepower developed by a steam turbine cannot be computed from an indicator diagram, as is done with reciprocating engines; in practice it is measured by means of some form of a dynamometer, as a Prony brake, for instance. For this reason, whenever the horsepower of a steam turbine is mentioned, the brake, or shaft, horsepower is meant. In the reciprocating engine the indicated horsepower is always given, unless distinctly stated otherwise. The indicated horsepower of such an engine is always much more, probably by 20 per cent. on an average, than the delivered horsepower, the difference being required to overcome frictional resistances within the engine.

PUMPING MACHINERY

935. What is a pump?

A **pump** is a machine for lifting or conveying fluids, and when not otherwise specified the word is generally understood to mean a machine for lifting and conveying water.

936. Define water.

Water is a liquid composed of 8 parts of oxygen and 1 part of hydrogen by weight.

937. What is the weight of a cubic foot of water?

The weight of a cubic foot of water at its maximum density (39.2° F.) is 62.425 pounds; at 32° F., or the freezing point, water weighs 62.4 pounds per cubic foot, and at 212° F., or the boiling point, water weighs 59.7 pounds per cubic foot.

938. Is water compressible?

Water is almost **non-compressible**; its compressibility is about 0.00005 of its volume under a pressure of 15 pounds per square inch, and it decreases with an increase of temperature; for practical purposes it may be considered as **incompressible.**

939. At what temperatures can water be handled by pumping machinery?

Pumping machinery can handle water only between the limits of the freezing and boiling points.

940. Explain how water flows into a pump when the pump is so located that the water must flow into its water chamber by atmospheric pressure on the surface of the water external to the suction pipe.

By the action of the pump, a vacuum of more or less perfection is produced in the water chamber. The end of the suction pipe is submerged, and the excess of pressure on the surface of the water outside of the suction pipe causes the water to rise in the suction pipe until the pressure due to the weight of the column equals the pressure of the atmosphere.

941. What is the pressure of the atmosphere?

For practical purposes the pressure at sea level is taken as 30 inches of mercury, or 14.7 pounds pressure per square inch. This atmospheric pressure becomes less as the altitude increases.

942. How would you find the maximum height in feet to which water can be lifted at sea level?

Since a pressure of 1 pound per square inch is equal to that exerted by a column of water 2.309 feet high, the maximum height that water can be raised by a perfect vacuum at sea level will be $14.7 \times 2.309 = 33.94$ feet.

943. How would you find the maximum height in feet to which water can be lifted at any altitude?

By multiplying the barometric reading in inches by 1.133.

944. How would you find the maximum lift for water holding foreign substances in suspension, or for other liquids?

By dividing the maximum height to which water can be lifted at the existing atmospheric pressure, as shown by the barometer, by the specific gravity of the liquid.

945. Why is the actual height to which pure water can be lifted only about .82 of the maximum possible height?

Because a perfect vacuum cannot be obtained on account of mechanical imperfections, and on account of the air contained in the water, and the vapor of the water itself. When pumps are located at the bottom of deep mines, the barometer will plainly show a greater pressure on the bottom than at the surface, and hence a greater suction lift is possible at the bottom.

946. Why is it difficult to lift water whose temperature exceeds 180°?

On account of the increased pressure of the vapor at the higher temperatures.

947. When required to handle hot water, how should pumps be located, and what valves should be provided?

Whenever possible, the pumps should be so arranged that the hot water will flow to them. They should be provided with suitable valves of vulcanized rubber for the lower temperatures and of metal for the higher temperatures. Soft rubber valves should never be used for handling hot water.

948. What limits the height to which water or any other liquid can be forced?

The height to which water or any other liquid can be forced is limited by the power available for forcing the liquid and the strength of the pump and the pipe connections. The atmospheric pressure has no effect on the height to which liquid can be forced.

949. What is a steam pump?

A pump in which the moving force is steam, which is applied to the movement of water without the use of belting or gear-wheels.

950. Into what general classes are steam pumps divided?

Direct-acting and **flywheel-pattern** pumps.

951. Give a general description of direct-acting steam pumps.

Direct-acting steam pumps are pumps in which the pressure of the steam in the steam cylinder is transferred to the piston or plunger in the pump in a direct line and through the use of a continuous rod or connection, and in which there are no revolving parts, such as shafts, cranks, and flywheels. In pumps of this construction the moving parts have no weight greater than that required to produce sufficient strength in such parts for the work they are expected to perform. There is no opportunity to store up power in one part of the stroke to be given out at another and, therefore, it is impossible to cut off steam in the cylinder prior to full stroke. The uniform and steady action of the direct-acting steam pump is dependent solely on the use of a steady, uniform pressure of steam throughout the entire stroke of the piston against a steady, uniform resistance of water in the pumps. The difference between the force exerted in the steam cylinder and the resistance in the pump governs the rate of speed at which the piston or plunger will move. The length of the stroke of the steam piston within these pumps is limited and controlled by the admission, release, and compression of the steam in the cylinder.

952. What can you state regarding the development of the direct-acting steam pump?

The direct-acting steam pump was invented by Henry R. Worthington in the year 1840 and was patented in 1841. A few years later Mr. Worthington developed and brought out what is now known as the **duplex** direct-acting steam pump.

953. What was the objection to the single direct-acting pump?

The objection to the **single** pump was the fact that the action of the pump plunger or piston was an intermittent one; that is, the column of water was started into motion at the beginning of each stroke and came to a stop at the end of each stroke, thus not only making the flow of water irregular, but also subjecting the pump and the connecting pipes and their joints to severe and often serious strains.

954. In what way does the duplex direct-acting steam pump differ from the single direct-acting pump?

In the main, the construction of the steam and water ends of the duplex pump differs but slightly from that of the single direct-acting pump, but the mechanism that operates the steam valves is different and the effect on the water column is very different.

955. Explain the principle upon which the duplex pump operates.

Two pumps of similar construction are placed side by side; a lever attached to the piston rod of each pump connects to the slide valve of the opposite steam cylinder, and thus the movement of each steam piston, instead of operating its own steam valve, as in the single pump, operates the slide valve of the opposite cylinder. The effect of this arrangement is that shortly after the piston, or plunger, of one pump passes beyond the middle of its stroke, the plunger, or piston of the other begins its movement, thus alternately taking up the load of the water column and producing a steady onward flow of water without the unusual strains induced by such a column of water when suddenly stopped or started.

956. What are the advantages of the direct-acting pump?

The direct-acting pump is the simplest form of pump yet devised; its action most nearly harmonizes with the laws controlling the action of water, and in the event of a conflict, the direct-acting pump will yield to the superior force of the water without serious resistance. The direct-acting pump is the most universally used type of pump in existence.

957. What are the disadvantages of the direct-acting pump?

The direct-acting steam pump is not economical, its design requiring the carrying of the full steam pressure throughout the whole stroke. This drawback prohibits its use in places where a high economy in the use of steam is imperative. By the use of a so-called **high-duty attachment,** however, the ordinary direct-acting pump can be and is converted into a machine using steam expansively. A fair degree of economy is also obtained by compounding the steam end.

958. Explain the valve motion of the Knowles steam pump.

An auxiliary piston works in the steam chest and drives the main valve. This auxiliary, or **chest piston,** as it is called, is driven backward and forward by the pressure of the steam, carrying with it the main valve, which in turn gives steam to the steam piston and operates the pump. The main valve is a plain slide valve of the B form working on a flat seat. The chest piston has a rod to which is clamped an arm, which is connected to a rocker bar by a link. The main piston rod carries an arm, which is provided with a stud, or bolt, on which there is a friction roller. This roller moves back and forth under the curved rocker bar with the motion of the main piston rod and lifts the ends of the bar, thus giving the chest piston a slight rotary motion just at the end of the stroke of the main piston. Each end of the chest piston is provided with a port, and the solid part of the steam chest has four ports, which open into the space in which the chest piston moves. Two of these ports connect with the live steam space in the steam chest and serve as steam ports, while the other two connect with the exhaust. When the main piston, under the action of steam, approaches the right end of the cylinder, the roller lifts the right end of the rocker bar, thus rotating the chest piston so as to bring its left end port in connection with the exhaust port and the port in the right end of the chest piston in connection with the right end steam port. This drives the chest piston and main valve to the right, allows the steam at the left of the main piston to exhaust, and admits live steam to the right of the main piston again. The chest piston, as it approaches either end of its chamber, covers the exhaust port at that end, thus confining enough of the exhaust steam to form a cushion to prevent it from striking the end of the steam chest. The main piston also covers the exhaust port before reaching the end of its stroke, so that it is cushioned by the exhaust and prevented from striking the cylinder head. Special passages are provided for admitting the steam required to move the piston far enough to uncover the main ports on the return stroke. The arm carried by the main piston rod carries a collar that slides over the chest piston rod, and in case the steam pressure is not sufficient to move the chest piston, this collar will strike one of the two collars carried by the chest piston rod, and thus move the valve.

959. Explain the valve motion of the Cameron steam pump.

The **Cameron** pump possesses the advantage of having no outside gearing. The action of the Cameron valve motion is as follows: The spaces at the ends of the chest piston communicate with the live-steam space by means of small holes. By means of these holes, these spaces and the ports leading from them are kept filled with live steam as long as the ports are covered by the piston valves. Let us assume that the pump is in such a position that the space in the main cylinder to the right of the piston is in communication with the live-steam space in the steam chest; the piston therefore moving to the left. When the piston strikes the stem attached to the left-hand reversing valve, it forces this valve to the left and uncovers the left-hand port, thus allowing the steam at the left of the chest piston to pass out through the exhaust. The steam to the right of the chest piston then expands and drives the chest piston and with it the main valve to the left, thus reversing the action of the steam on the main piston, which immediately begins to move back toward the right. Live steam is always acting on the reversing valve, so that as soon as the main piston moves to the right, this steam pushes the left-hand reversing valve back and covers the left port again, after which live steam fills the port and the space connected with it through the small holes in the end of the chest piston. When the main piston strikes the stem of the right-hand reversing valve, the main valve is again shifted to the right and the main piston is started on its stroke to the left. The main piston, as it approaches either end of its chamber, covers the exhaust port at that end, thus confining enough of the exhaust steam to form a cushion to prevent it from striking the cylinder heads.

960. Explain the valve motion of the Gordon pump.

If the load is suddenly thrown off from the ordinary direct-acting steam pump through any cause, the steam is liable to drive the piston to the end of its stroke with so much force as to cause serious shocks or even to break some part of the pump. In order to overcome this danger the Gordon steam pump is provided with an arrangement, which is called an **isochronal valve-gear.** In this gear the main valve is operated by a double chest piston, which is actuated by steam controlled by an auxiliary slide valve in a small steam chest. This auxiliary slide valve is provided with a valve stem, to which two collars are fastened with set-screws. A slide, which receives its motion from the main piston rod by means of links, a lever, and cross-head, strikes the two collars near the ends of the main piston stroke, thus moving the auxiliary valve and admitting steam to the double chest piston, which in its turn operates the main steam valve and reverses the motion of the main piston. The slide carries a cylinder in which works a piston fastened to the rod of the double chest piston. This cylinder, called a **cata-**

ract cylinder, has a cock that controls a passage joining its two ends, and by means of this cock the passage may be more or less closed, as desired. The object of the **cataract cylinder** is to eliminate the danger of the main piston's striking the heads with enough force to break them, if the load is suddenly thrown off. It is filled with liquid, which must be forced from one end to the other by motion of the piston. By partly closing the cock in the passage from one end of the cylinder to the other a resistance is opposed to the passage of the liquid, and the motion of the piston through the **cataract cylinder** may be made as slow as desired; consequently, when the main piston moves too rapidly, the motion of the slide on the main piston rod will be transmitted to the piston in the cataract cylinder, which will shift the main valve so as to shut off the supply of steam to the main piston and thus prevent the pump from running too fast.

961. Explain the valve motion of the Marsh pump.

The **Marsh valve motion** operates without any connection to the piston or rod. The steam piston is made in two parts, each section being provided with a packing ring so arranged as to provide an annular space between the two piston valves. Steam at boiler pressure is admitted within the pistons by means of a tube, which is rigidly secured to and is in communication with a chamber in the cylinder head. A stuffing-box in the piston through which this tube plays prevents leakage into the main steam cylinder. A small port supplies steam to the chamber in the cylinder head. When the piston is moving to the right, steam is entering from the steam chest through the annular opening between the reduced neck of a piston valve and the bore of the left chest wall. The steam is projected against the inside surface of the left valve head before escaping through the port and passing into the cylinder. Both the pressure and the impulse due to the velocity of the entering steam act on this valve head and tend to force it to the left, thus tending to close the annular opening in the left chest wall. The steam flowing into the cylinder also flows through small ports to the left of the left valve head. The steam entering through these ports is wiredrawn, so that its pressure is reduced, but it has a greater area of the valve head exposed to its pressure than the steam on the right of the same valve head. Hence, the valve moves to a position where the total forces acting on the two sides of the left valve head are equal and then remains stationary. The steam entering through the annular opening in the left chest wall is also wiredrawn, so that the pressure on the left of the piston is below the full boiler pressure existing in the steam chest. While the piston is moving to the right, the steam on the right of piston is exhausting into the exhaust port. The exhaust is first closed by the piston, running over the port. As soon as this port is covered, a small port leading to the right of the right valve head communicates with the space within the piston containing steam at boiler pressure, and this live steam rushes into the space to the right of the right valve head. Since the steam pressure on the left of the left valve head is less than the pressure on the right of the right valve head, the valve moves to the left, and by doing so closes the left steam inlet, opens the left exhaust, and also opens the right steam inlet in the chest wall. The live steam admitted to the right of the piston first brings it to rest and then reverses its motion. Two tappets at the ends of the chest are used for moving the valve by hand in case the valve is stuck.

962. What types of duplex and single direct-acting pumps are there?

Duplex pumps, like single direct-acting pumps, are made either as **piston** pumps or as **plunger** pumps. When made as plunger pumps, they may have either **inside-packed, center packed,** or **outside-packed** plungers. Piston pumps are preferred for moderate pressures, but for pumping against very high pressures the plunger pump is generally used.

963. How are steam valves of a Worthington duplex direct-acting steam pump operated?

The steam valve for one cylinder is worked from the crosshead of the piston rod of the other cylinder through a lever. This lever is keyed to a shaft that passes through a standard and carries a crank in line with it at the other side of the standard, and to this crank is attached the valve rod. The valve rod in turn is hinged to the valve stem. The steam valve is carried along by coming in contact with check-nuts on the valve stem, so placed that there is some lost motion between them and the valve. By this means the steam piston is caused to be at rest for a short time at the end of the stroke, which allows the water valves to seat quietly.

964. How is the piston cushioned in a Worthington slide-valve duplex pump?

There are two ports communicating with each end of the steam cylinder, of which the outer ones are the steam ports and the inner ones the exhaust ports. By this arrangement, when the piston approaches the end of its stroke, it covers the exhaust port and thus confines some steam in the cylinder that serves as a cushion.

965. How are the valves operated in a piston-valve Worthington duplex pump?

The valves are operated in practically the same manner as those of the slide-valve pump, but the lost motion instead of being between the valve and stem is obtained by a special construction of the valve rod. This rod is divided into two parts. The part attached to the valve stem carries a slotted yoke; the part attached to the crank is free to slide within the yoke and carries a collar pinned to it. The collar alternately strikes against the check-nuts on the yoke and then carries the valve with it. The lost motion is quite large as the valve needs to be moved but a slight amount.

966. Explain how the dash relief valves of a Worthington pump control the length of the stroke and keep it constant.

These valves control passages connecting the steam ports and exhaust ports, and are set by trial to the correct position and then locked with the cap nuts. When the piston on its exhaust stroke covers the exhaust port, no further exhaust can take place, and the steam will be compressed between the piston and the cylinder head. The location of the exhaust port is so chosen that the compression will stop the piston just short of the cylinder head at the highest speed at which the pump can operate. When the pump is working at slow speed, the compression being the same as at high speed but the momentum of the moving parts being less, the piston will stop earlier than at high speed and the stroke will be shortened. The **dash relief valves** provide an escape for the exhaust steam after the exhaust ports are closed and thus regulate the amount of compression to suit the speed of the pump, and the length of stroke is thus kept constant. **Dash relief valves** are applied to pistons of over 14 inches, and are used with slide-valve pumps as well as with piston-valve pumps.

967. What is the purpose of making direct-acting steam pumps multiple-expansion?

The simple direct-acting steam pumps are very extravagant in the use of steam, because no use can be made of the expansive force of the steam. In order to overcome this waste to a greater or less extent, many of the larger pumps are made with either compound or triple-expansion cylinders.

968. Explain a common method of arranging the cylinders for a compound duplex pumping engine, and their action.

The engine for each pump is made with two cylinders arranged tandem, the valves for both cylinders being driven from the same valve stem. The high-pressure cylinder is placed outside and connected to the low-pressure cylinder by a cast-iron yoke, or spacer, which forms one head for each cylinder. The high-pressure piston rod passes through a sleeve in this spacer. The sleeve is a free fit in the body, and is free to adjust itself slightly. The exhaust passes directly from the high-pressure cylinder through a pipe to the steam chest of the low-pressure cylinder. Since there is no cut-off in either cylinder, the back pressure on the high-pressure piston is at all times equal to the forward pressure on the low-pressure piston, neglecting the resistance to the flow of steam through the pipe and ports.

969. In a compound pumping engine, what is the number of steam expansions equal to?

Since the volume of steam admitted during each stroke is equal to the volume of the high-pressure cylinder, and this steam, when exhausted, just fills the low-pressure cylinder, the number of expansions is equal to the ratio of the volume of the low-pressure cylinder to that of the high-pressure cylinder. Also, since the length of stroke is the same for both cylinders, the number of expansions is equal to the ratio of the areas of the low- and the high-pressure piston. The usual number of expansions for small and medium sizes ranges from two to three. For large sizes four expansions are sometimes used.

970. Explain the purpose and action of the so-called cross-exhaust connection in compound direct-acting steam pumps.

The purpose of the **cross-exhaust** is the keeping of a more uniform pressure in the steam chests of the low-pressure cylinders than obtains otherwise. It is simply a pipe of ample size, which is provided with a valve and connects the steam chests of the low-pressure cylinders. With this valve open, the exhaust from the high-pressure cylinder of one pump can pass to the low-pressure steam chest of the other pump just when the pressure in that steam chest commences to drop, and in consequence the pressure will be kept more uniform, which results in a steady and uniform motion.

971. Explain the purpose of the high-duty attachment to direct-acting steam pumps.

The purpose of the **high-duty attachment** is to convert the ordinary direct-acting steam pump into a machine using steam expansively, by storing up power during the first half of the stroke and giving it out again during the second half.

972. What are flywheel steam pumps, and what is gained by their use?

They are steam engines with cranks and flywheels usually designed for the particular purpose of driving the pump to which they are attached. The steam valves are driven in the ordinary way by means of eccentrics, or some approved automatic valve gear may be used to operate them. By the use of the flywheel, steam may be cut off at the most economical point in the stroke, and the surplus energy imparted to the steam piston during the first part of the stroke will be stored in the flywheel, to be given up toward the end, thus furnishing a nearly uniform driving force for the pump piston, or plunger.

973. Explain, in a general way, the construction of a rotary pump.

Generally a **rotary pump** consists of a chamber in which two toothed wheels, or disks, revolve. The teeth of one wheel fit accurately into the spaces between the teeth of its mate. As the wheels revolve, each tooth acts as a piston that pushes a certain amount of water ahead of it, thus drawing the water from the lower part of the chamber to the upper part. It is very important that the flat faces of these wheels, or disks, should be a good fit between the cover and the bottom of the casing or cylinder, and the edges of the teeth also a good fit against the sides of the casing. **Rotary pumps** differ from each other principally in the number and shape of the teeth on the rotating disks. The shafts of the two disks are provided with outside gearing that makes their relative motion positive and always keeps them in their proper relative position. The toothed wheels, or disks are called **impellers.**

974. Explain, in a general way, the construction of a screw pump.

The **screw pump,** which is a form of rotary pump, has two shafts side by side and connected by gears. Each shaft carries a right-handed and a left-handed screw, and the right-handed screw of one shaft meshes with the left-handed screw of the other shaft. The water coming through the suction pipe flows through passages in the casing to the outer ends of the screws and is drawn toward the center by the revolving screws, from whence it is discharged through the discharge pipe. The screws closely fit the pump casing and are a close running fit on each other. Since the screws are right-handed and left-handed and the course of the water is toward the centers from the ends of the four screws, there is no end thrust. The pump may be driven by a belt placed on a pulley, or an engine or electric motor may be connected directly to it.

975. Describe the centrifugal pump and its action.

The **centrifugal pump** depends for its action on the pressure produced by the centrifugal force of a quantity of water rotated rapidly by the vanes of the pump. When the vanes are revolved, the air between them is driven out by centrifugal force, thus forming a partial vacuum. Water is forced in through the suction pipe by the pressure of the atmosphere and fills the space between the vanes. The water is made to revolve with the vanes, and the action of the centrifugal force drives it outward into a spirally shaped passage, which leads it to the discharge pipe connected to the outlet.

976. Explain the advantages and disadvantages of centrifugal pumps.

For low heads and large quantities of water **centrifugal pumps** give excellent results, and are especially useful when the water contains grit or other impurities that would destroy the pistons and packing or prevent the closing of the valves of other pumps. Since there are no valves or other restricted passages, these pumps have been largely used in dredging machines, for pumping water containing large quantities of mud, sand, and gravel. In fact, anything can be pumped that will be carried through the pump and pipes by a current of water. Simple **centrifugal pumps** are most efficient when working under low heads and are seldom used for heads greater than 40 feet. They may be belt-driven or be direct-connected to an engine or other motor. **Multi-stage** pumps comprise a series of simple pumps, and are efficient at high heads (one discharging into another).

977. What is meant by a power pump?

A pump in which the piston or plunger is driven by a crank that receives its motion through a belt or gearing from some outside source of power, is usually called a **power pump.**

978. What is a single power pump?

A **single power pump** is one in which but one pump is driven by the shaft. This pump may be either single-acting or double-acting.

979. What is a duplex power pump?

A **duplex power pump** is one in which two pumps or plungers are driven by cranks on a single shaft.

980. How are the discharge branches and cranks of duplex power pumps arranged so as to give a steady flow?

The **discharge branches** from the two pumps are combined in such a way that they discharge through a single pipe. If the pumps are single-acting, the cranks are set 180° apart. The discharge from the two pumps will be the same as the discharge from one double-acting pump with the same diameter of piston and length of stroke. If the pumps are double-acting, the cranks are set 80° apart. When one crank is on its dead center and its piston is at the end of its stroke and momentarily at rest, the other piston is moving at about its maximum velocity and discharging at its maximum rate.

981. What is a triplex power pump?

Three pumps or plungers driven by cranks on a single shaft form a **triplex pump.**

982. Describe the most common type of triplex power pump used.

The most common type of **triplex pump** consists of three single-acting plunger or piston pumps driven by cranks set 120° apart on a single shaft. With such a combination, at least one of the pumps is always discharging while one is taking water from the suction pipe, and the flow is therefore continuous and nearly uniform.

983. Why is the belt-driven power pump the most economical pump to use?

Because they get their power with practically the same degree of economy as the engine by which they are driven. They are also simple in construction and easily operated.

984. Why are nearly all mine pumps of the plunger pattern?

Because, the plunger pump, by reason of the ease with which leakage can be stopped, is best adapted for high pressures.

985. What is meant by a pit pump?

A pump having its water end located at the bottom of the mine and connected to a steam engine or other motor at the surface by rods. Pit pumps are the oldest type of mine pump and are still used to some extent.

986. What are some of the objections to lift pumps when used for mining purposes?

The pump rod, being inside the delivery pipe, reduces the effective area of pipe and increases the friction of the water to some extent, owing to the added surface rubbed against. The rods are concealed and cannot be inspected without removing the entire rod. The bolts and rods sometimes break, thus rendering their recovery difficult, and the bolts wear against the stocks, causing loss of power by friction and destroying the pipes. Lift pumps, however, are not so liable to sudden injurious strains as the force pump.

987. In what respects is the force pump superior to the lift pump for mine work?

The **force pump**, which is almost invariably of the plunger pattern, is superior to the lift pump in nearly every respect for very high lifts or when dirty water is being raised. When pumping against a heavy pressure, it is impossible to keep the pistons of lift pumps tight and prevent the water from leaking. The piston and the cylinder of the lift pump must be a perfect fit and be truly cylindrical. With a plunger pump, the rod passes through a stuffing-box, and the plunger may or may not fit the cylinder. When pumping dirty water the grit comes in contact with the surface over which the piston of a lift pump is constantly traveling, and destroys both the cylinder and piston very rapidly; whereas the plunger has to be kept tight at only one permanent place, and the dirt cannot very well get at the surface of the packing on which the plunger or plunger rod rubs. Every part of a plunger pump can be readily examined and repaired without the operator's being obliged to take down the whole apparatus.

988. Describe the construction of a lifting pump for use in mines.

The pump consists of a series of pipes connected together. A part of the pipe forms the pump cylinder in which a piston works. The part above the highest point of the piston travel is the delivery pipe, and the part below the lowest point of the piston travel is the suction pipe. In mine pumps, the delivery pipe is usually termed the **working barrel,** and the suction pipe the **wind bore.** In mine pumps, the lower end of the wind bore is pear-shaped and perforated with many small holes to help keep solid matter in the water from entering the pump and destroying the valves. In some cases, the pear-shaped end is covered with gauze for the same purpose. Two bonnets are provided. One gives access to the suction valve, the other to the piston and its valves. The pump rod is made of wood strapped with iron.

989. Briefly describe the sinking pump and the purpose for which it is used.

When putting down a new shaft or deepening an old one, the **sinking pump** is used to drain the water from the shaft bottom so that the work may proceed. These pumps are portable and are suspended by a chain attached to eyebolts in the pump. They are also provided with wrought-iron clamps, by means of which they may be attached to the timber in the shaft when it is desired to fix them in position temporarily. As the shaft gets deeper, the chain may be lengthened out, and an extra joint placed on the upper end of the delivery pipe, and the pump is again ready for business. While most sinking pumps are steam-operated, electrically driven sinking pumps are also used. The electric motor is placed within a water-tight casing above the water end, so that the pump can work just as well under water as above it.

990. What kinds of direct-acting steam pumps are used for mine drainage?

Direct-acting steam pumps used for mine drainage are almost invariably of the plunger pattern. Most of them are duplex, but a number of single double-acting steam pumps are in use. Formerly, all the mine steam pumps were simple direct-acting pumps, but of late years compound and even triple-expansion pumps have grown in favor, and even crank-and-flywheel pumps driven by compound Corliss engines are now extensively used on account of their superior economy. Most of the pumps are of the **double-plunger type,** there being two plungers to each water cylinder, and the stuffing-boxes are located on the outside, thus making the pumps **outside packed.** Some mine pumps are **center-packed** and use but one plunger for each water cylinder.

991. **What is meant by a displacement pump?**

A pump in which there are no moving parts and where the fluid to be pumped is moved by steam or compressed air.

992. **What are the advantages of the pulsometer?**

When the barometer stands at 30 inches, the **pulsometer** will raise water by suction to a height of about 26 feet, and force it to a height of 100 feet. It has no wearing parts whatever, except the valves, which are easily and cheaply replaced. It will work in almost any position, and when once started requires no further attention. There are no parts that can get out of order. It will pump anything, including mud, gravel, etc., that can get past the valves. Its first cost is low and it requires no foundations to be set up. There is no exhaust steam to make trouble, and no noise.

993. **Briefly describe the direct-air-pressure pump and its action.**

In the **direct-air-pressure** pump, there are two pump tanks, which are fitted with suction and discharge valves. The two tanks are connected to a common suction pipe and both discharge into the same discharge pipe. The tops of the pump tanks are connected by pipes to an air compressor, and by means of an automatically operated four-way cock, either tank can be connected to the compressor side of the air compressor. With the four-way cock in a certain position, tank No. 1 is connected to the suction side of the air compressor, and hence a vacuum is formed in that tank. Consequently, the water in the supply is forced by atmospheric pressure up the suction pipe, through the suction valve, and into the tank. At the same time tank No. 2 is connected to the compressor side of the air compressor, and the air pressure on top of the water forces it out, the water holding the suction valve closed but opening the delivery valve and passing up the discharge pipe. When this tank is nearly empty, tank No. 1, connected to the suction side of the air compressor, is nearly full; the four-way cock is then turned automatically so as to bring tank No. 2 in communication with the suction side of the air compressor, and tank No. 1 in communication with the compressor side. The water now flows into tank No. 2, and out of No. 1, and the cycle of operations is repeated as long as the air compressor is working. The height to which the water can be forced depends on the pressure to which the air is compressed.

994. How are pump plungers usually constructed?

In smaller sizes of pumps, plungers are usually made of solid round bars of metal turned smooth, so as to work through a stuffing-box with as little friction and wear as possible. For larger sizes the plungers are frequently of cast-iron and are often made hollow to reduce the weight and amount of material required. A hollow plunger is easier to move than a solid one, due to the fact that the water buoys up a hollow plunger more than a solid one. In large horizontal pumps hollow plungers are often so proportioned that they actually float in the water, thus relieving the stuffing-boxes of the weight of the plungers and reducing the wear.

995. How are plungers packed when used under heavy pressure?

When the pressure under which the pump works is very heavy, U-shaped leather packing is sometimes used. The **cup leather,** as it is called, is held in a recess cast in the upper end of the pump cylinder. In such case it is necessary to remove the plunger in order to insert a new leather or to examine an old one. The leather bears against the plunger with the greatest force at the bend and fails at that point first. In some plungers the leather is held in its recess by a gland and is also supported by a brass ring, which prevents the severe pressure of the leather against the plunger at the bend. In more elaborate packing the gland is lined with a brass ring, which holds the leather down on a brass supporting ring. A chamber in the gland serves to hold oil for lubricating the plunger.

996. What are the most important disadvantages of the inside-packed plunger pump?

When the packing becomes worn, the heads of the pump cylinder must be removed in order to tighten or renew it, and, besides, there is no way of detecting leakage when the pump is working.

997. Briefly explain the construction of pump pistons.

Pistons for force pumps are made in a variety of forms. Some are packed with fibrous packing held in place by a follower. The follower is fastened to the piston by means of an extension of the piston rod beyond the nut that holds the piston in place. Some small pistons consist of three metallic parts, between which are clamped two cup leathers. Pistons for suction and lift pumps are provided with valves that allow free passage for the water through the piston in one direction and prevent its return.

998. Mention the conditions that pump valves are required to fulfil.

They must open freely under a light pressure. The net area of the passages through the valves should be great enough to limit the velocty of the flow through them to 240 feet per minute. The lift of the valve should be small. The passages for the water should be as direct as possible. The valves must close tightly under all conditions. The valves and their seats must be durable and of such material as is not easily affected by the impurities in the water. The valves must return to their seats quickly and without shock as soon as the current through them is stopped. The valves and seats must be easily repaired or removed when worn.

999. Explain the disk valve construction.

The **disk valve** is a type much used in all classes of pumps for ordinary pressures and service. The valve consists of a vulcanized India-rubber disk that rests on a gun-metal or brass seat. The seat is threaded so that it can be screwed into the deck of the valve chamber and thus can be easily removed. The valve is either fastened to a spindle, which is guided by a cage-shaped guard screwed on to the valve seat, or the spindle is screwed into the valve seat and carries a guard. A helical spring between this guard and the plate helps to seat the valve quickly. When used for pumping hot water, the disk must be made of a composition that will not be affected by the heat. Metal disks are also used for very high pressures.

1000. In what sizes are disk valves made?

The size of these valves varies from 2 to 6 inches in diameter, the most common size for ordinary conditions being 3 inches.

1001. What is meant by the valve deck of a pump?

The part of the pump chamber that contains the valves is called the **valve deck,** and it is spoken of as the **suction valve deck** or **delivery valve deck** in accordance with the kind of valves it carries.

1002. Describe the construction of a clack-valve.

A **clack-valve** consists of a leather disk held at one side and strengthened by a metal plate on top. The leather when wet forms an excellent hinge and a tight valve.

1003. What is meant by a double seat valve?

A valve in which there are two seats and two openings for discharge.

1004. Briefly describe the wing valve.

The **wing valve** is largely used in power pumps for feeding boilers and in hydraulic pumps for high pressures. The valve and seat are made either of hard brass or of gun-metal and are ground together to secure tight closing. The lower portion of the wings is sometimes curved, so as to give the valve a partial rotation at each stroke of the pump. This makes it seat at a new place at each stroke and tends to wear the valve and seat more evenly.

1005. What is meant by an air chamber in connection with a pump?

A vessel containing air which is attached either to the pump just outside of the discharge valves or to the discharge pipe near the pump.

1006. What is the purpose of an air chamber?

In all pumps there is an interruption of the flow at the end of the stroke, when the piston changes its direction of motion. This brings the column of water in the suction and discharge pipes to rest at the end of each stroke. If the pipes are long, the force required to stop and start the water will be very great, and there will be a severe shock at the end of every stroke that will absorb power and subject the pump and pipes to great stresses. This difficulty is removed and the flow through the pipes is made more continuous and steady by the use of an air chamber.

1007. Explain the principle of action of a delivery air chamber.

The water, after being drawn in through the suction pipe past the suction valves, is forced by the pistons or plungers past the discharge valves into the discharge pipe, part of it flowing into the air chamber and compresing the air therein. When the plunger reaches the end of its stroke and no more water is being forced into the discharge pipe, the compressed air in the air chamber forces the extra water out through the discharge pipe in a nearly steady stream. The air in the air chamber also acts as a spring that absorbs the extra force during the inward stroke of the plunger and gives it out during the return stroke, thus relieving the pump and pipes of shocks and providing a nearly constant rate of flow from the discharge.

1008. What should be the size of a delivery air chamber?

The size of an air chamber on the delivery side depends upon the type of pump, the speed at which it works, the length of the discharge pipe, and the pressure head against which the pump works. For ordinary double-acting pumps working against moderate pressures and at ordinary speeds, the cubical contents of the air chamber should not be less than 3 times the piston displacement. For pressures of 100 pounds per square inch and upward, or for high piston speeds, the capacity of the air chamber should be at least 6 times the volume of the piston displacement for a single stroke.

1009. How is the air lost from the air chamber and what is the effect of such loss?

Under the increased pressure in the air chamber, the air is absorbed by the water and gradually passes off with it. In this way all the air will finally pass off and the chamber will be made useless. Therefore, some means should be provided for renewing the supply of air to the chamber.

1010. Why are alleviators used instead of air chambers when pumps work under pressures greater than that due to a 350-foot lift?

When the pressure is greater than that due to a 350-foot lift, air chambers are not of very much service, owing to the fact that the air escapes from the air chamber either through the pores of the iron or at the joints, or it is rapidly absorbed and carried off by the water, and the air chamber gives the pump no relief whatever. **Alleviators** are used to overcome this defect.

1011. Briefly explain the construction of an alleviator and where it should be placed.

An **alleviator** consists of a plunger working through a water-packed stuffing-box. On top of the plunger are arranged springs that may be in the form of rubber buffers or helical coil springs. When the pressure in the pipe exceeds the working pressure, the plunger is forced out through the stuffing-box and relieves the pump of the shocks that would otherwise occur. **Alleviators** may be placed anywhere on the delivery pipe, but are preferably placed in such a position that the direction of the moving water is in line with the plunger of the **alleviator.**

1012. What is the purpose of an air chamber on the suction pipe?

With a long suction pipe or a pipe with numerous bends and valves, the resistance to the flow of the water through it is considerable. In some cases this resistance is so great that the pressure of the atmosphere is not sufficient to set the column of water in motion quickly enough to fill the pump chamber as fast as the piston moves. This makes the action of the pump imperfect and causes a severe blow, called the **water hammer,** when the piston again meets the inflowing water. The **suction air chamber,** or the **vacuum chamber,** as it is often called, will remedy this difficulty. In its general form it resembles an air chamber, but the pressure in it, instead of being greater, is always less than the atmospheric pressure. When the pump is drawing water, the air in the vacuum chamber expands and forces the water below it into the pump. At the same time the atmosphere forces water in through the suction pipe to balance the reduced pressure in the vacuum chamber. The vacuum chamber is again partly filled and the air in it is compressed during the discharge stroke of the pump. It thus acts as a reservoir that receives from the suction pipe a nearly steady supply, which is given up intermittently to the pump.

1013. What should be the size of the vacuum chamber?

For ordinary cases, the vacuum chamber may be made half the size of the discharge air chamber working under the same conditions. A good rule is to make the cubic capacity of the vacuum chamber for a single pump twice the displacement of the piston for a single stroke.

1014. Where should an air chamber be located?

Both suction and delivery air chambers should, if possible, be placed at a bend in the pipe and close to the pump, and in such a position as to be in line with the flow of water in the pipe. If placed at right angles to the flow of water, their efficiency is somewhat impaired. The suction and delivery air chambers of large pumps should be provided with glass water gauges so that the height of the water can be determined at a glance.

1015. What materials should be used for the building of pump foundations?

Pump foundations should be built of hard brick laid in cement mortar, of concrete, or, in the case of large pumps, of stone, if it can be readily secured.

1016. How should pumps be held down to their foundations?

All pumps should be held down by foundation bolts. In the case of small pumps the bolts should be provided with a steel or wrought-iron plate washer built solidly into the foundation, while large pumps should have tunnels or pockets for access to the lower foundation washers and nuts. If the foundation bolts are built in solidly, box washers should be used.

1017. Describe the general construction of foundations for large vertical pumps.

In the case of large vertical pumping engines, the masonry required to form the pump pit and to support the superstructure is of ample mass for all foundation purposes. In this class of pumping engine, large arched chambers and tunnels are often used to save foundation materials. These large pumping engines are often located at or near a water supply where the soil has not sufficient rigidity to support the weight. In this case piling must be resorted to, on which the foundation proper is constructed.

1018. In building pump foundations, what precaution should be taken with reference to the foundation bolts, and suction and delivery connections?

A foundation templet should always be used, in which the foundation-bolt holes are carefully laid off, preferably from the actual castings. The various heights of bosses or thicknesses of casting through which the bolts pass should also be marked on the templet. The templet should be carefully set with reference to the suction and delivery connections, so that when the pump is set up, the fittings and pipes will connect up properly.

1019. In the case of large pumps, how are the pipe connections arranged?

In the case of large pumps it is customary to arrange the pipe connections in such a way that a short space is left between the piping and the pump. This space is then measured after the pump and piping are in place, and a **distance piece** is made to suit the measurement and then put in place.

1020. What precautions should be taken in setting up small pumps of the single-cylinder and duplex type?

When bolting down the steam and water ends, care must be taken not to twist or throw the pump out of line. To prevent the pump from being thrown out of line, it is best to have one of the supports rigidly bolted down to the foundation, while the other end is left free. In making the steam and water connections, the pipes should come fair to their connection and should not be sprung into place. Stresses on the pump structure due to winding foundation surfaces and sprung pipe connections should be guarded against, particularly with steam-thrown valves, as these are very sensitive and must be free. Any slight springing of the valve chamber will bind the valve and prevent its operating.

1021. Why must the location of the source of supply of the liquid to be pumped be taken into consideration before a pump can be properly located?

Since the atmospheric pressure of 14.7 pounds to the square inch will balance a column of water only 34 feet high, the pump must not be placed more than 34 feet vertically above the surface of the liquid to be pumped. But since a perfect vacuum cannot be obtained by mechanical means, and since the flow of the liquid is retarded by friction in the pipes and passages, the limit of vertical lift by atmospheric pressure is reduced to about 28 feet at sea level in actual practice. The actual lift, like the maximum possible lift, varies with the atmospheric pressure, and will therefore become smaller with an increase of altitude above sea level, since the air becomes lighter and its pressure less. The pump should, therefore, be placed as near the source of supply of liquid to be pumped as is possible, both vertically and horizontally.

1022. What precautions should be taken in designing the suction pipe?

The suction pipe should be as straight as possible. If bends are necessary, they should be made by bending the pipe to a long radius or by using long-turn fittings. The suction pipe should be of one diameter from end to end. If from necessity the suction pipe is very long, it will be well to increase the size somewhat, the reduction at the pump chamber should then be made by a long conical fitting. For ordinary service pumps the diameter of the suction pipe should be such that the velocity does not exceed 200 feet per minute. If the suction pipe is made small, the pump will fail to fill and the plunger will strike the incoming water on its return stroke, producing a violent and dangerous shock. If the vertical lift be high, a suction air chamber and a **foot-valve** should be provided.

1023. What is meant by a foot-valve?

A check-valve placed at the lower end of the suction pipe below the water level in the source of supply and opening toward the pump is called a **foot-valve.**

1024. What are the advantages and disadvantages of a foot-valve?

When the water does not flow into a pump and has to be lifted by suction, a **foot-valve** should be provided. It will prevent the suction pipe from emptying while the pump is at rest and will prevent the water in the suction pipe from slipping back while running. This will insure a prompt starting of the pump, provided that the **foot-valve** is tight enough to hold the water in the suction pipe. In very cold weather and in exposed locations, however, the **foot-valve** is an element of danger when the pump is out of use, since it prevents the emptying of the suction pipe. The water in the suction pipe may freeze and burst the pipe. To prevent this, a drain should be fitted to the lower end of the suction pipe just above the foot-valve, and used in cold weather to empty the suction pipe when the pump is shut down.

1025. When foot-valves are used, why is it advantageous to place a relief valve on the suction pipe?

Generally, the suction pipe is made considerably lighter than other parts of the pump, and if the suction valves should leak when the pump is standing or if the priming pipe be left open, the full pressure of the delivery water will come on the suction pipe and foot-valve, which are not usually designed to withstand such pressures. A relief valve, set to relieve the pipe at a pressure well within its safe strength, will prevent overstraining the suction pipe from this cause.

1026. What kind of foot-valves are preferable?

Foot-valves that are of simple construction, of the weighted-lift type or clack valve type. They should have at least 50 per cent. excess of area over the suction pipe.

1027. Describe the settling chamber and its purpose.

If the water to be pumped is gritty or contains foreign substances, a **settling chamber** is sometimes used. It consists of an iron box conveniently arranged in a horizontal pipe. It is usually of large relative capacity, a settling chamber for a 2 inch pipe being 2 feet by 2 feet by 3 feet long. The pipes enter and leave from opposite sides and near the top. The increased volume of the large box allows the water to move very slowly across the box, giving the suspended foreign substances time to settle to the bottom. The settling chamber should have a removable cover for the purpose of removing the settlings. This device is used on small pumps working on artesian wells.

1028. Describe the suction basket and strainer used for keeping back foreign matter from the working barrel of the pump.

The **suction basket** consists of a box variously shaped, and perforated with strainer holes or provided with screens, which is placed on the bottom of the suction pipe. The **strainer** consists of a chamber placed in the suction pipe, located in an accessible position and provided with strainer plates so made that they can be readily removed for cleaning. This strainer is sometimes connected directly to the pump. A short piece of pipe between the strainer and the pump will avoid interference when removing the water-cylinder heads. The objection to the suction basket on the bottom of the suction pipe is its inaccessibility for cleaning and inspection.

1029. What precautions should be taken in designing the delivery pipe?

A careful adjustment between the supply and delivery pipes should be made in order to produce the best effect from the whole plant. The delivery pipe should as far as possible be a plain, straight pipe from pump to terminal. When bends are necessary, they should be made with sweeps as long as possible. A **gate-valve** or **check-valve** should be placed near the pump. The check-valve serves the double purpose of relieving the pump of pressure when starting up, allowing it to take hold of the water more quickly, and also of holding the water back from the pump when inspection and repairs to the water end are necessary. If a check-valve is not used, a gate-valve should be placed at or near the pump delivery to hold back the water in case repairs are made to the pump end, or in case of accident. This valve should always be a straightway gate-valve giving the full clear opening of the pipe. If the delivery pipe is made small, the cost of power required to force the water through the pipes at a high velocity will very quickly overrun the cost of a larger pipe.

1030. With what velocity should the water be permitted to flow through the delivery pipe?

The velocity of the water flowing through the delivery pipe with direct-acting pumps should not exceed 330 feet per minute, while for large crank-and-flywheel pumping engines the velocity of the water in both suction and delivery pipes is about 300 feet per minute.

1031. What is a water-end by-pass pipe on a pump and what is its object?

A **water-end by-pass** is a pipe connection from above to below the delivery-valve deck. In the case of compound pumps, when starting up, the force of the full steam pressure on the high-pressure piston is not sufficient to move the plungers against the resistance due to the head of water in the delivery pipe. By opening the valve in the by-pass piping, the pressure on the plungers is relieved for a sufficient number of revolutions to allow the steam to reach the low-pressure piston, when the combined force of the two pistons will do the work, and the by-pass pipe can be closed. On crank-and-flywheel pumps the by-pass water pipes have another function. Unless these machines are fitted with very large flywheels, they can often not be run as slowly as may be desired. By opening the valve in the by-pass pipe, part of the water can be returned to the pump chamber and the amount of water actually pumped reduced to any desired quantity permitted by the size of the by-pass. This, however, is accomplished at a very considerable loss of efficiency, because it takes the same power to move the by-pass water as it does to do the actual pumping. By-pass pipes are usually made of area equal to 2½ per cent. of the plunger area.

1032. What is a steam-end by-pass on a pump and what is its object?

A **steam-end by-pass** is a pipe connection which allows high-pressure steam to act on the low-pressure steam piston in starting. By-pass steam pipes are also used for warming up the low-pressure cylinder and connections, and in the case of crank-and-flywheel pumps to move the high-pressure crank off the dead center.

1033. What is a priming or charging pipe on a pump and what is its object?

It is a small pipe run from the delivery pipe beyond the check-valve or delivery gate-valve to the suction chamber of the pump. Its object is to fill the working chamber and suction pipe with water, taking up all clearances and helping the pump to take hold of the water quickly. This pipe may have an area from ¾ of 1 per cent. to 1 per cent. of the area of the plunger. In the case of long inclined or horizontal suction pipes a pipe much larger than 1 per cent. of the plunger area will be required.

1034. Explain the object and operation of a waste delivery or starting pipe on a pump.

The object of a **waste delivery** or **starting pipe** is to relieve the pump of air when the pump becomes **air bound.** This pipe is fitted with a valve and connected to the delivery pipe close to the pump. When the pump is air bound, it is well to run with the valve open until the water flows to the pump and is discharged into the delivery pipe.

1035. When is a pump said to be air bound?

It often happens that a pump refuses to lift while the full pressure against which it is expected to work is resting on the delivery valves, for the reason that the air within the pump chamber is not dislodged but only compressed and expanded again by the motion of the plunger. A pump in this condition is said to be **air bound.**

1036. Why is it that a pump will sometimes refuse to start when a check-valve has not been placed in the delivery pipe, and how is this remedied?

When a check-valve is not placed in the delivery pipe and the delivery pipe is full of water, the pump will often refuse to start the water in the suction end, owing to compressed air being trapped between the water in the delivery deck and suction valves. To remedy this, **air discharge valves** are used on each head. Each of these valves is composed of a globe valve and a check-valve. The check-valve opens to the atmosphere, thus permitting the escape of air but preventing its entrance when the globe valve is open. The globe valve is closed when the pump is working properly, as shown by the water coming from the check-valve.

1037. What precaution should be taken when designing the general piping arrangement for pumps, with regard to freezing?

Proper drain pipes and drain valves should be provided for all parts of the pump and pipe connections in which water may remain when the pump is not in use, where it may give trouble by freezing. Provision for draining **the suction valve deck** and **the delivery valve deck** is sometimes made by drilling a small hole through the decks. While this practice is simple and cheap, it leads to a loss of efficiency, since some of the water is constantly flowing back into the suction chamber.

1038. Mention some of the causes of loss in efficiency of steam pumps.

Losses in efficiency arise from wear, from improper adjustment, from the wrong timing of the various movements that control the distribution of steam, by leakage, by decreased mechanical efficiency due to lack of alignment, by accumulations of foreign matter on and in condenser tubes, suction strainers, and foot-valves, in suction and delivery pipes; and in many minor directions.

1039. Are there any specific rules for the management of pumps?

No. Pumps differ so much in their construction and design that it is entirely impossible to lay down specific rules that will be applicable to every pump. The general rules must be modified by the pump attendant to suit every specific case.

1040. Describe how the dirt and grit can be removed from the steam piping and cylinder and valve seats of a new steam pump.

After the steam piping is in place, but before it is finally connected to the pump, all valves in it should be opened wide. The steam should be turned on slowly, and allowed to flow through the piping and valves quite liberally. This will clear the piping of all foreign matter collected therein during erection. The piping having been blown out throroughly, steam is shut off and the piping is then connected to the pump. The piston and valves should be removed from the steam end of the pump so that there is a clear passage for the steam from the boiler to the exhaust. The cylinder heads should be put on. The stuffing-boxes should be closed, which can be done by placing a piece of board between the stuffing-box and the reversed gland and then setting up the nut on the stuffing-box studs. When the gland is drawn home by a nut outside of it, a circular piece of pine board may be placed between the end of the gland and the inside of the nut in order to close the opening through which the piston rod presses. The steam may then be turned on. By opening the throttle valve wide open at short intervals, the sand and scale in the ports and other passages and spaces of the steam end can be blown out. After the cylinders have been blown out, the heads and covers should be removed, and all foreign matter blown into the corners and chambers of the cylinder should be removed by hand. The pistons, valves, cylinder heads, and other covers should then be put in place.

1041. **Describe the manner of keying up a pump of the crank-and-flywheel type.**

The pump should be turned a complete revolution by hand to insure that everything clears properly and that no tools or materials used during construction or erection have been left within the machine. The adjustment of all journals, pins, and bearings should then be made. With gib and key ends, it is usual to drive down the key with a soft hammer until it is home, mark it, drive it back, and then tap it down to within 1/8 inch of the mark. With wedge ends, the wedges usually have an inclination of 1 1/2 inches per foot and the adjusting screw has 8 threads per inch. The wedge is drawn up solid and then the adjusting screw is turned back about 20 degrees and locked. Bolted connecting-rod ends are allowed about 1/200 inch play, using liners and setting the bolts up solid. Main bearings can be adjusted best when the machine is in motion.

1042. **Describe the manner of packing the rods and stems of a pump.**

If fibrous packing is used, the boxes should be filled full and the glands tightened down very moderately. The tightening of the glands can best be done when steam is on and the machine is in motion, when they should be tightened sufficiently only to stop leakage and no more. When excessive tightening is required to stop leakage, the packing should be completely renewed. If pumps are fitted with metallic packings, the makers' directions for use should be carefully followed. In case of unsatisfactory results, the makers should be consulted.

1043. **What precautions should be taken with regard to the oiling of pumps?**

All rubbing surfaces should be provided with suitable oiling devices. The quality of oil should be carefully selected to suit the velocity and pressure of the rubbing surfaces on which it is used. For use within the steam cylinder, heavy mineral oil, the only oil capable of withstanding the high temperature, should be selected. In starting up new pumps, it is best to use the highest grade oils for the first month, as this practice will go far toward reducing subsequent oil bills. Pumping engines are often required to run continuously and should therefore be provided with oiling devices so arranged that they can be supplied and adjusted while the machine is in motion. It is a good plan to provide two separate sets of oiling systems for all the principal journals, so that if one system fails the other can be used while the disabled one is being overhauled. In starting up new machines the bearings should be flooded with oil at first to wash out any dust or grit that may have reached the rubbing surfaces.

1044. **What precautions should be taken in starting a crank-and-flywheel pump?**

Having turned the machine by hand and inspected all locknuts, setscrews, and clamp screws, the engine may be put under steam. If provided with hand starting gear, this should be used for a sufficient number of turns to make sure that the machine is free from water. All drain cocks should be open when starting and relief valves should be adjusted to blow at the proper pressure. If the engine is to run condensing, connections from the exhaust port to the condenser should be made absolutely tight. If an independent condenser is used, it should be started before the main pump is started and a vacuum obtained in advance.

1045. **Why is the direct-acting pump not so liable to an accident in starting as the crank-and-flywheel pump?**

Because the kinetic energy stored up in the flywheel of a crank-and-flywheel pump is absent in a direct-acting pump.

1046. **In starting a new direct-acting steam pump with dash relief valves, what precaution should be taken with regard to the relief valves?**

The **dash valves** should be closed in order to keep the pistons as far from the heads as possible, for in new installations accidents are liable to happen at the water end, and to prevent danger of a breakdown, as in case of a sudden lunge of the piston, all the margin possble to keep them from striking the heads should be gained.

1047. In starting a pump, what precaution should be taken with regard to conditions at the water end?

The plungers and plunger rods should be properly packed and the plunger grease cups, if any, should be filled. If the machine is compound or triple-expansion, the water by-pass valves must be opened until the machine has made a sufficient number of strokes to bring the intermediate and low-pressure cylinders into action, when the by-pass valves should be closed. The suction pipe from the foot-valves to the delivery valve deck must be absolutely tight, because any leakage will cause the water end to work improperly. All the suction valves and delivery valves should seat fairly and tightly. Care must be taken that the valves in the delivery pipe are open, because the margin in driving force over the resistance is sufficient to burst the water end, particularly if the momentum of a flywheel be added to it. The lower end of the suction pipe should be kept well under water, as a slug of air taken into the pump may cause a violent jumping and, in a direct-acting pump, possibly a striking of the steam pistons against the heads.

1048. Why should gauges be attached to both the suction and delivery pipes of pumps?

Gauges should be attached to the suction and delivery pipes, and they should be carefully watched during the process of starting, because trouble at the water end will be promptly recorded by them.

1049. What precautions should be taken regarding the delivery air chamber of a pump?

The delivery air chamber should be carefully watched, particularly during the starting. This air chamber should be provided with a gauge glass showing the height of the water and the extent of pulsation. The air chamber should be charged with air when the air in the chamber disappears. Large pumps are usually supplied with an air charging pump that is attached to and driven by the main pump, or an arrangement of pipes and valves is sometimes applied for this purpose. In very large pumping plants, an independent air compressor or locomotive air pump is often used for this service.

1050. **When a pump is running, how can a good idea of the internal working of the water end be obtained?**

By placing the ear against the pump chambers, the seating of the valves can be distinctly heard, and if there is any leak past either the suction or delivery valves, it can also be heard.

1051. **Mention some of the most common causes of troubles with the suction end of pumps.**

Some of the most common causes of trouble with pumps are leaks below the suction valves. They may be at the joints or along the suction pipe or in the pump chamber, and may be due to imperfect connections, leaky chaplets, shifted cores, blowholes, corrosion, or cracks from frost.

1052. **If the piston of a pump jumps, or moves suddenly, during the first part of the stroke, what is the cause?**

Small leaks in the suction end, and leaky valves and plungers, will cause the piston to move suddenly during the first part of the stroke. If this is the case, the leaks should be repaired and the valves and plungers should be refitted and repaired.

1053. **In pumping hot water, if the pump works with a jerky action, what is the trouble and how may it be remedied?**

The trouble is that the lift is too high for the temperature, and one or the other must be reduced. If possible, it is always best to have hot water flow to the pump by gravity.

1054. **In pumping hot water from wells, what precaution should be taken?**

In pumping from wells, care should be taken that the pump is near enough to the water to prevent the water from falling below the maximum lift by suction.

1055. If a pump pounds soon after the beginning of a stroke, when running fast, what may be the trouble, and how may it be remedied?

Pounding after the beginning of a stroke shows that the pump chamber is not filling and that the plunger is striking the incoming water on its return stroke. This may be due to the effect of a suction strainer or to the end of the suction pipe becoming clogged with foreign matter. The obstruction should be removed. Pounding in pumps is also caused by water lagging behind the plunger, due to friction of a small, long, horizontal suction pipe. When suction pipes have a long horizontal run, they should be one or two sizes larger.

1056. Explain how air pockets are caused under the delivery valve deck, and what effect they have on the efficiency of a pump.

Air pockets under the delivery valve deck are caused either by bad design or by a shifting core. The effect of the air pocket is to entrap air, which is compressed to delivery-water pressure and expands again on the suction stroke. This defect, however small, will always reduce the suction lift, which will very much reduce the capacity and efficiency of the pump. This defect is not easy to remedy, and its presence should always be cause for the rejection of a pump.

1057. What troubles at the delivery end may cause a pump to fail and how may these be remedied?

Pumps sometimes fail when the full head is resting upon the delivery valves because the air between the suction and delivery valves is expanded and compressed by the motion of the plunger. To remedy this, air cocks should be provided close up under the delivery decks for discharging the air until the plungers have caught the water. If only a simple cock is fitted, it must be opened during the delivery stroke only and closed shortly before the suction stroke commences. This is to be repeated until a steady stream of water issues from it during the delivery stroke. An automatic air valve, opening outwardly and closing automatically during the suction stroke, is preferable. This valve should be secured to its seat after a steady stream of water issues during the delivery stroke.

Violent jarrings and tremblings of the pump arise from the delivery air chamber's becoming filled with water. It should be recharged with air by means of the air-chamber pump, a near-by air compressor, or by a hand air pump.

1058. If at any time it becomes necessary to dismantle a pump, what precautions should be taken?

If it becomes necessary to dismantle a pump, all the parts should be plainly marked with steel letters or numbers, rather than with a prick punch or chisel, and suitable gauges, by which all parts can be returned to their correct relative positions, should be made, if this is deemed advisable. If the parts are interchanged the pump will not run successfully. In placing the gasket between the valve chest and cylinder of pumps with steam-thrown valves, care should be taken to cut passages through the gasket for the auxiliary ports. The steam end of pumps should not be taken apart needlessly, especially the steam end of direct-acting pumps with steam-thrown valves.

1059. What is the effect of too little or too much lost motion between the valve stem and valve of a duplex pump?

Too little lost motion will cause short stroking, while too much will allow the pistons to strike the heads.

1060. If the piston strikes the cylinder heads or the stroke is too short, how can the trouble be remedied?

If the pistons strike the cylinder heads, the lost motion between the valve stem and the valve should be made smaller; if the stroke is too short the lost motion should be increased. If the pump is fitted with dash relief valves, they should be partly closed when the piston strikes the heads and opened when the stroke is too short.

1061. When a compound pump, fitted with a cross exhaust, is unable to complete its full stroke, what should be done to remedy the trouble?

The valve in the cross exhaust should be opened.

1062. How can leaks in the suction pipe of a pump be detected?

Leaks in the suction pipe can sometimes be detected by the ear, or the flame from a common tallow candle will often locate a leak in the suction by being drawn toward the hole by the air. Sometimes the leaks are so small that any one of them would be difficult to locate, yet they are so numerous that their combined effect is sufficient to affect the working of the pump. The best way to locate these leaks is to stop up the inlet end of the pipe, uncover it completely, and then put a water pressure on it from 40 to 50 pounds per square inch. Any leaks, however small, will then be readily detected.

1063. What effect have leaks in the suction system and delivery pipe on the working of a pump?

Leaks are the most troublesome and most frequent sources of loss of efficiency in pumping machinery. Leaks in the suction pipe or suction system affect the pump most, and often cause its complete failure. Leaks in the delivery pipe do not affect the action of the pump or its efficiency to any such great extent, the loss being exactly proportional to the magnitude of the leak.

1064. How should leaky pipes be repaired?

The most satisfactory method of procedure is to discard the leaky section of pipe and replace it with a new one. Circumstances, however, do not always permit this to be done, and then temporary repairs should be made. The manner of making the repairs depends on the position and extent of the leak and calls for the exercise of judgment and skill.

1065. How can pinholes in the suction pipe be stopped up?

Pinholes in the suction pipe can generally be stopped by a thick coat of red-lead putty spread over the pipe where the leaks occur. This should be covered with several layers of canvas, covered on both sides with red-lead putty and wound as tightly as possible around the pipe. The canvas should then be secured by wrapping it with strong twine or annealed copper wire, put on as tightly as possible. A permanent repair in case of pinholes can be made by drilling out the pinhole with a twist drill and tapping out the hole. A closely fitting threaded plug of soft steel or wrought iron is then screwed in and the end riveted over.

1066. How can a split suction pipe be temporarily repaired?

This can be done by covering the split part with a piece of sheet metal, preferably sheet lead, bent to the curvature of the pipe and put on with red-lead putty. The canvas should then be wrapped over this.

1067. How can leaks in the delivery pipe be repaired?

Small pinholes can be repaired by drilling out the pinholes with a twist drill, tapping out the holes and screwing in closely-fitting threaded plugs of soft steel or wrought iron, and riveting over the ends. If the leak is extensive, however, it will be necessary to use a **pipe clamp.** Such clamps are made in many different ways, according to the location and extent of the leak and the facilities for repair.

1068. How should air chambers be tested for leaks, and the leaks repaired, if discovered?

They are usually tested by closing all openings and then pumping air into them until the working pressure is reached, as shown by a pressure gauge. If after 24 hours this gauge does not show any reduction of pressure, the chamber is tight. If the gauge shows a reduction of pressure, the leaks may be found by filling it with water subjected to the working pressure. If there are a number of leaks, the chamber should be condemned; if only a few small leaks exist, they can be stopped by drilling a hole at the leak and screwing in a plug.

1069. Describe the method of testing the plungers of inside-packed or center-packed plunger pumps for leakage, and the manner of repairing leaks if discovered?

The manner of testing will depend on their design, the general method of procedure being the subjecting of one side of the plunger to an air pressure or hydrostatic pressure at least equal to the working pressure. If leaks are discovered, judgment has to be used as to the manner of repairing them or whether to condemn the plunger. In some designs of inside-packed and center-packed pumps with closed hollow plungers, the weight of the plunger is so proportioned to its displacement as to relieve the stuffing-boxes of nearly all of its weight; it is then important that they be absolutely water-tight.

1070. How can leakage past the piston in piston pumps, and past the plunger in inside-packed plunger pumps, be detected?

If the leakage is extensive, it can be heard by placing the ear against the pump chamber. It is best with this style of pump to make regular inspections for leakage past the piston or plunger, providing suitable pipes and apparatus by means of which pressure can be put on one side of the packing or piston while the other side is exposed for inspection.

1071. Describe the method of testing for leakage past the suction and delivery valves of pumps.

The delivery and suction valves should be tested separately, because the fact that the column of water in the delivery pipe does not drain out while standing is not proof that both sets of valves are tight, since either set will support the water while the other set may be leaking badly. To test the suction valves for leakage, disconnect the suction pipe or take any other convenient steps that will allow the leakage to be seen. Fill the delivery pipe full of water, having removed enough delivery valves to allow the pressure to reach all the suction valves, and observe which valves, if any, are leaking. When there is a valve in the delivery pipe, this may be shut and water pumped into the pump cylinder with a small force pump, running the pressure up to the working pressure. The delivery valves can be tested by filling the delivery pipe or by closing the valve in the delivery pipe and pumping water into the delivery pipe between its valve and the pump delivery valve. The pump chamber must be open so that the leaks can be seen.

1072. What is meant by surging of water in pipes, and where does this condition often exist?

By **surging** of water through pipes is meant that the velocity of flow is not constant, and that the direction of flow reverses for a short period. This condition often exists in pumping machinery having very long suction or delivery pipes. It may occur in either of the two pipes, but it is most severe in the delivery pipe. Crank-and-flywheel pumps, owing to the variation in the piston speed between the beginning and end of the stroke, are particularly liable to produce surging, which is due entirely to an irregular delivery.

1073. Why are duplex direct-acting pumps less liable to cause surging than crank-and-flywheel pumps?

Duplex direct-acting pumps, owing to the uniformity of delivery and the absence of heavy weights, such as flywheels, are little liable to cause surging. For this reason this pump is chosen when liquids must be moved through long mains as for instance, through long oil pipe lines. Crank-and-flywheel pumps forcing water through very high delivery pipes, as in mine work, are seriously affected by the surging of the water.

1074. In the case of surging of water, in high delivery pipes, do air chambers help the matter any?

No. They probably aggravate it by forming an elastic cushion for the column of water to rebound from.

1075. In high delivery pipes, what is the effect of surging water?

The effect of surging water is to vary the pressure on the pump and mains, sometimes from zero to twice the pressure due to the vertical height, resulting in broken pump chambers and pipes, and damage to the working parts of the pump, for the actual resistance to these shocks is not met until they arrive at the flywheel rim.

1076. Why is surging in suction pipes not so serious as in delivery pipes?

Surging in the suction pipe is not so serious as in the delivery pipe for the reason that the direction of the force resulting from the surge is through the pump valves and into the delivery, or in the natural direction of the water, while the shock due to surging in the delvery pipe comes against the valves and must be withstood by the machinery.

1077. What means are employed to prevent shocks due to surging from reaching the machinery?

To prevent shocks from reaching the machinery, a large air chamber is needed on the suction main near the pump, and in addition spring-loaded relief valves may also be fitted to the main. These relief valves simply limit the pressure due to an unusually heavy surge that cannot be taken care of by the air chamber.

1078. In pumping a mixture of water and air, as for instance, in mine and artesian-well work, what trouble is encountered and what is the remedy?

When a mixture of water and air is pumped, the pump will have a jerky motion, and in the case of direct-acting pumps there is danger of striking the cylinder heads. Besides, on account of the uneven discharge, there will be violent disturbances in the delivery pipe. The only effectual remedy is to remove the air before it arrives at the pump.

1079. In pumping a mixture of water and air, how can the air be removed before reaching the pump?

A large suction air chamber is put into the suction pipe. A vacuum pump is connected by a pipe to the top of the air chamber and this not only maintains a vacuum in the chamber, but draws the air and gas out of the water in the chamber before it reaches the pump. The air chamber is provided with a gauge glass, which not only shows the height of the water in the chamber, but also allows the bubbles of air and gas rising through the water to be seen. The vacuum pump is running constantly and its speed is regulated to suit the height of the water in the air chamber.

1080. Describe the method of setting the valves of a duplex steam pump.

The steam valves of the duplex pump have no outside or inside lap, consequently when in their central position they just cover the steam ports leading to opposite ends of the cylinders. With all these valves a certain amount of lost motion is provided between the jam nuts and the valve. This lost motion in small pumps is within the steam chest, while in large pumps it is outside and may be adjusted while the pump is in motion. To set the valves in a duplex pump, remove the steam-chest bonnets, place the pistons in their mid-stroke position and set the valves central over the ports. Adjust the locknuts so as to allow about $\frac{3}{16}$ inch lost motion on each side. Move each valve each way until it strikes the nut or nuts and see if the port openings are equal. When the port openings have been equalized, the valves are set. The valve motion should not be disturbed while setting the valves. If only one valve of a duplex pump is to be set, it must be borne in mind that it is operated by the piston of the opposite pump. Place that piston in its mid-position and then set the valve as explained above.

1081. **Describe the process of placing the pistons of a duplex pump in their mid-stroke position.**

To do this, open the drip cocks and move each piston by prying on the crosshead, but never on the valve-lever, until it comes into contact with the cylinder head. Make a mark on the piston rod at the steam-end stuffing-box gland. Move each piston back until it strikes the opposite head, and then make a second mark on the piston rod. Half way between the first and second marks make a third one. Move the piston again until the last mark coincides with the face of the gland and the pistons will be exactly in their mid-stroke position.

1082. **What is meant by the displacement of a pump?**

The **displacement** of a pump is the volume of water that would be driven out of the cylinder by the piston or plunger in a given time if there were no slip or leakage.

1083. **In calculating the displacement of a pump in a given time, what must be taken into consideration?**

Care must be taken to consider the number of strokes during which water is discharged. With the double-acting pump the number of strokes during which discharge occurs is equal to the total number of strokes that one piston makes, while with the single-acting pump water is discharged only when the piston moves in one direction and, therefore, the number of strokes during which discharge occurs is equal to one-half the total number of strokes that the piston makes. With a duplex double-acting pump, it is customary when giving the number of strokes per minute to refer only to the number of strokes made by one piston, which is only one-half the total number of strokes made. As practice varies, however, among engineers in this respect, it is best to find out in each case whether the number of strokes of one piston or of both pistons in a given time is meant when the number of strokes is given. In the case of a crank-driven pump, for a single single-acting pump the strokes will be equal to the revolutions of the crank; for a single double-acting and a double single-acting crank-driven pump the stroke will equal twice the number of revolutions; for a triplex single-acting crank-driven pump the strokes will equal three times the number of revolutions; and for a triplex double-acting pump, six times the number of revolutions.

1084. Give a rule for calculating the displacement of a pump per minute in cubic feet, gallons, or pounds.

Multiply the length of the stroke in inches by the mean effective area of the pump piston or plunger in square inches and the number of strokes per minute. The product is the displacement in cubic inches per minute. To reduce the displacement to cubic feet, divide by 1,728; to reduce to pounds, multiply inches by the weight of a cubic inch of the liquid pumped; to reduce to U. S. standard gallons, divide inches by 231; to reduce to English imperial gallons, divide inches by 277.27.

1085. How many different gallons are in use, and what are their measurements?

There are three different gallons in use, of which the U. S. standard, or wine gallon, measuring 231 cubic inches, is most commonly used in America. The imperial gallon holding 277.27 cubic inches, is largely used as a measure in Great Britain. The beer or ale gallon measuring 282 cubic inches is also used in most English-speaking countries, but almost exclusively for measuring the liquids mentioned.

1086. How is the mean effective area of a pump piston or plunger found?

In the case of outside-packed plunger pumps, the mean effective area of the plunger or piston is equal to the area corresponding to the diameter of the plunger or piston. In the case of inside-packed and center-packed plunger pumps and double-acting piston pumps, the mean effective area is found by dividing the sum of the piston or plunger area, and the same area less the area of the piston rod, by 2.

1087. What is the difference between the displacement and the actual discharge of a pump?

The displacement of a pump is the volume swept through by the piston or plunger. The **actual discharge** is less than the **displacement**, owing to slip or leakage past the valves and piston and also to the return of water through the valves while they are in the act of closing.

1088. What is meant by the total slip of a pump?

The difference between the displacement and the actual discharge, expressed as a percentage of the displacement, is called the **slip** of a pump.

1089. When is the slip of a pump said to be negative?

When the column of water in the suction and discharge pipes of a pump is long and the lift moderate, the energy imparted by the piston during the discharge stroke may be sufficient to keep the column in motion during all or a part of the return stroke. Under these conditions, the actual discharge may be greater than the displacement, and the slip is then said to be **negative.**

1090. Give a rule for calculating the slip of a pump.

To calculate the **slip** of a pump, find the difference between the displacement and the actual discharge, multiply it by 100, and divide the product by the displacement. The quotient will be the slip of the pump expressed in per cent. of the displacement.

1091. Give a rule for finding the useful work in foot-pounds done by a pump.

Multiply the water raised in pounds by the vertical distance in feet from the surface of the water in the well or supply reservoir to the outflow end of the discharge pipe. The product is the **useful work** in foot-pounds done by the pump.

1092. Why is the actual work done by a pump always greater than the useful work?

Because force is required to overcome the friction of the piston or plunger in the cylinder or stuffing-box, and the friction of the water in its passage through the pipes and the valves and passages of the pump. Some force is also expended in giving the water the velocity it has when it leaves the discharge pipe.

1093. Give a rule for finding the theoretical and actual force required to drive the piston of a pump.

The **theoretical force** required to drive the piston is found by multiplying the area of the piston by the pressure due to a head equal to the vertical distance from the surface of the water in the well to the outlet of the discharge pipe. The **actual force** can be found by the aid of a pressure gauge or indicator attached to the pump cylinder, which will give the actual pressure on the piston in pounds per square inch.

1094. How can the force required to drive the piston of a pump be reduced?

By reducing the frictional resistance of the water which can be accomplished by making the pipes large and direct and the passages through the valves and pump of ample size and as direct as possible.

1095. Give a rule for finding the horsepower of pumps.

The indicated horsepower developed in the cylinder or cylinders of steam-driven or compressed-air-driven pumps is found in exactly the same manner as with a steam engine and from the same data. The horsepower usefully expended is given by dividing the useful work done by the pump in 1 minute by 33,000.

1096. Give a rule for estimating the probable horsepower required to drive a pump, assuming an efficiency of 70 per cent.

To estimate the probable horsepower required to drive a pump, multiply the weight to be discharged per minute by the vertical lift and divide by 23,100. (The problem of estimating the probable horsepower required to drive a pump can only be solved approximately by the above general rule, there being a number of variable factors entering into the solution, such as the general arrangement and length of the piping, the design of the water end, etc.)

1097. In estimating the probable horsepower, it is occasionally necessary to convert a given pressure into a head of water in feet that will exert the same pressure. How can this be done?

This can be done by multiplying the given pressure in lb. per sq. in. by 2.3.

1098. When the weight of water to be discharged per minute and the pressure against which it is to be pumped are known, and assuming an efficiency of 70 per cent., what is the rule for finding the probable horsepower required to drive a pump?

Multiply the weight of the water to be pumped per minute by the pressure pumped against and divide by 10,043.

1099. Give a general rule for estimating the vertical lift of a pump with a given horsepower.

To estimate the vertical lift with a given horsepower, multiply the horsepower by 23,100 and divide by the weight of water to be delivered per minute.

1100. How can the probable discharge in pounds per minute be estimated?

To estimate the probable discharge in pounds per minute, multiply the horsepower by 23,100 and divide by the vertical lift in feet, or multiply the horsepower by 10,043 and divide by the pressure to be pumped against in lb. per sq. in.

1101. Give a rule for estimating the probable pressure that can be pumped against with a given horsepower.

Multiply the horsepower by 10,043 and divide by the weight to be pumped per minute.

1102. In determining the size of a piston or plunger for the water end of a pump, what must be taken into consideration?

Before the size of a piston or plunger for the water end of a pump can be determined, the quantity of the water to be pumped and the piston speed must be known. If the pump is duplex, it is advisable to consider only one side in determining the size of the piston or plunger, designing it to suit one-half the total quantity of water to be delivered. In direct-acting steam pumps, it is customary to design the piston or plunger under the assumption that the piston speed is about 100 feet per minute and then to run the pump faster or slower to suit the required delivery, opening or closing the throttle valve to vary the speed of the pump. The fact that there is always more or less slip of the water should also be taken into consideration, and the piston or plunger should be designed under the assumption that it must pump 1.25 times the actual amount of water.

1103. What is meant by the term the piston speed of a pump?

The piston speed is the number of feet traveled per minute by the plunger when **discharging** water. The piston speed equals the length of the stroke in feet multiplied by the number of **working** strokes per minute. If the pump is double-acting, the number of working strokes is the same as the total number of plunger strokes of one plunger, both forward and back; if simple-acting, half that number.

1104. Give a rule for determining the diameter in inches of a plunger or piston required.

Multiply the discharge in cubic feet per minute by 229 and divide the product by the piston speed in feet per minute. Extract the square root of the quotient.

1105. **Give a rule for estimating the probable discharge of a pump in cubic feet.**

Square the diameter of plunger or piston in inches and multiply by the piston speed. Divide the product by 229.

1106. **Give a rule for roughly estimating the probable normal discharge of a direct-acting steam pump in gallons.**

Square the diameter of plunger or piston in inches and multiply by 3.26. For a duplex pump, multiply this last product by 2.

1107. **Having determined the proper plunger or piston diameter for the chosen piston speed, and having chosen a length of stroke, give a rule for finding the number of strokes.**

Divide the piston speed in feet by the chosen length of stroke in feet.

1108. **If the piston speed in feet and the number of delivery strokes per minute are known, give a rule for finding the length of stroke in feet.**

Divide the piston speed in feet by the delivery strokes per minute.

1109. **What are the two factors on which depend the size of the steam-end cylinder in a direct-acting steam pump?**

They are the steam pressure available and the resistance against which the pump is to force the water.

1110. **Why is the area of the steam piston made at least 40 per cent. in excess of that which is strictly necessary?**

This is done in order that there may be an ample margin to overcome frictional resistances, which make the actual resistance to the motion of the water piston greater and lessen the force that impels the steam piston forward.

1111. **Give a rule for finding the minimum diameter of the steam piston required for a given direct-acting steam pump.**

Multiply 1.8 times the area of the water piston in square inches by the pressure in pounds per square inch to be pumped against; divide by the available steam pressure and extract the square root of the quotient.

1112. **Does the above rule apply only to direct-acting steam pumps?**

No. It applies equally well to steam- and air-driven pumps. It can also be applied to simple pumps of the crank-and-flywheel type using steam expansively. In the latter case, the mean effective pressure throughout the stroke must be taken as the available steam pressure. This rule is especially useful in deciding whether a given pump will pump against a known pressure with the existing sizes of steam and water pistons. It is also useful in selecting a pump for a given service from the catalogues of manufacturers.

1113. **In boiler feed pumps, why is it necessary to make the area of the steam piston much larger than the area of the water piston?**

In boiler feed pumps, the steam pressure available and the pressure pumped against are practically equal, and it is necessary to make the area of the steam piston about 40 per cent. larger than the area of the water piston. Pump manufacturers, however, prefer to make the steam piston 3 times the area of the water piston in very small pumps and about twice the area of the water piston in large pumps. The reason for making the steam piston so largely in excess of what it really needs to be is to insure a prompt starting of the pump under almost all conditions likely to arise in practice.

1114. **What is meant by the term "the duty of the pump"?**

The ratio between the work done by the pump and a certain quantity of coal, steam, or heat units used to do the work is called the **duty** of the pump.

1115. **When the duty of a pump is based on the consumption of coal, it is customary to assume 100 pounds of coal as the fuel unit. Give a rule for finding the duty of a pump per 100 pounds of coal.**

Multiply together 100, the weight of the water pumped in a given times in pounds, and the vertical distance in feet from the level of supply to the level of discharge. Divide the product by the coal consumption in the same time in pounds.

1116. **When the comparison of the merits of two pumps is based on the coal consumption, what conditions must be taken into consideration and why?**

The coal must be of the same quality and the boilers supplying the steam to the pumps must be of the same type or at least must have the same evaporative economy. One hundred pounds of good bituminous or anthracite coal may, under favorable conditions, furnish 1,000 to 1,100 pounds of steam to the pump. One hundred pounds of coal, however, if of inferior quality and burned under a poor boiler, will not furnish the pump more than 450 to 600 pounds of steam.

1117. **Give a rule for finding the duty of a pump per 1,000 pounds of dry steam.**

Multiply together 1,000, the weight of the water pumped in a given time in pounds, and the vertical distance in feet from the level of supply to the level of discharge, and divide by the weight of dry steam used in the same time, in pounds.

1118. **When the duty of a pump is based on the steam consumption, why is it customary to assume 1,000 pounds of steam as the unit?**

It is the custom of some pump makers to specify that the coal consumption shall be estimated on the supposition that a pound of coal evaporates 10 pounds of water, or, in other words, furnishes 10 pounds of steam to the pump. If one pound of coal is assumed to furnish 10 pounds of steam, 100 pounds of coal will furnish 1,000 pounds of steam.

1119. **Which is better adapted for pump duty trials, the basis of 1,000 pounds of dry steam or that of 100 pounds of coal?**

The basis of 1,000 pounds of dry steam is more scientific and better adapted for duty trials than that of 100 pounds of coal, but it is open, nevertheless, to objections. Not only is it difficult to determine the exact weight of dry steam entering the pump, but also 1,000 pounds of steam at 160 pounds pressure will do more work in the cylinder than 1,000 pounds of steam at 60 pounds pressure. If scientific accuracy is sought, the pressure of the steam should be specified in addition to the weight.

1120. **Why did the American Society of Mechanical Engineers in 1891 recommend that the number of British thermal units supplied be used as a basis for the estimation of the duty of a pump, instead of the coal or steam consumption?**

Because, when comparison of the merits of two pumps is to be made, one of the pumps may be at a disadvantage on account of the poor quality of the coal or the inefficiency of the boiler used. If each is allowed 1,000 pounds of dry steam, there may be an inequality because of the difference in the steam pressure in the two cases. If, however, each pump is furnished with an equal number of heat units, the merit of each pump can be gauged by the use it makes of the heat units furnished it, that is, by the ratio of the work performed to the number of heat units supplied.

1121. **When the number of B.t.u. is used as a basis for estimating the duty of a pump, why is it customary to assume 1,000,000 B.t.u. as a basis?**

A pound of good coal when burned produces about 13,500 to 14,000 B.t.u. A boiler of fairly good efficiency will utilize perhaps 10,000 of these B.t.u., the rest being lost by radiation, in the production of chimney draft, and in other ways. From 100 pounds of coal the boiler is able to extract 100 × 10,000 = 1,000,000 B.t.u., which are given up to the pump. Roughly speaking, about 1,000 to 1,100 B.t.u. are equivalent to a pound of steam. Therefore, 1,000 pounds of steam are equivalent to about 1,000 × 1,000 = 1,000,000 B.t.u. For this reason, the American Society of Mechanical Engineers recommended that the new basis for estimating the duty of a pump should be 1,000,000 B.t.u.

1122. **Explain how the number of foot-pounds of work done by the pump is found.**

A pressure gauge is attached to the discharge pipe and a vacuum gauge to the suction pipe, both as near the pump as convenient; then the net pressure against which the pump plunger works is equal to the sum or difference in the pressures shown by these two gauges increased by the hydrostatic pressure due to the difference in level of the points in the pipes to which they are attached. In case the gauge in the suction pipe indicates a vacuum, the sum of the pressures indicated by the gauges is taken, but when the water flows into the suction pipe under a head, so that the suction gauge indicates a pressure above the atmospheric pressure, the difference in the two pressures indicated by the gauges is taken. The number of foot-pounds of work done during the trial is equal to the continued product of the net area of the plunger in square inches (making allowance for piston rods), the length of the plunger stroke in feet, the number of plunger strokes made during the trial, and the net pressure in pounds per square inch against which the plungers work.

1123. Give a rule for finding the pressure corresponding to the vacuum in inches indicated by the gauge on the suction pipe.

Multiply the gauge reading in inches by .4914.

1124. Give a rule for finding the pressure corresponding to the difference in the level of the two gauges in feet.

Multiply this difference in feet by .434.

1125. Give a rule for determining the duty of a pump per 1,000,000 B.t.u.

Multiply the net pressure against which the plunger works, in pounds per square inch, by the net area of the plunger in square inches, by the average length of stroke in feet, the total number of delivery strokes made during the trial, and by 1,000,000. Divide the product by the total number of B.t.u. supplied during the trial.

1126. Explain how the duty of a pump is sometimes based on the volume or weight of water pumped.

In large plants where the pressure pumped against is either constant or practically so, a record is often kept for the purpose of comparing the performance of the plant from week to week or month to month with its former performances. The records may be kept in gallons pumped per pound of coal; in cubic feet pumped per pound of coal; in weight of water in pounds or tons pumped per pound of coal; or the record may be kept per ton or bushel of coal, etc. Duty computed on such a basis is spoken of as **gallon duty, cubic-foot duty, pound duty, ton duty,** etc. Such a record of duty is very valuable in showing variations in efficiency of a given plant at different times, but it cannot be used as a basis of comparison of the performances of different pumping plants. The records are sometimes kept in terms of quantity of water pumped per dollar, instead of quantity of water pumped per pound of coal; the records then show variations in efficiency in their commercial light.

1127. In what terms is it best to express the duty of a pump?

It depends upon the purpose for which it is required that the duty be known. If the duty is merely required to be known in order that the performances of a given pump at different times may be compared with one another, the duty may be based on coal consumption, steam consumption, or volume pumped per some unit of coal or money. But, if the performance of a pump is to be compared with that of others working under entirely different conditions, the foot-pound of work done per 1,000,000 B.t.u. is the only true basis of comparison.

1128. What are the average duties for the various types of pumps per 1,000 pounds of steam used?

Small direct-acting pumps for general service have a duty of 15,000,000 foot-pounds per 1,000 pounds of steam used. Compound direct-acting pumps of 5,000,000 gallons capacity in 24 hours should give a duty of 50,000,000 foot-pounds per 1,000 pounds of steam used. Large municipal pumping engines of 20,000,000 gallons' capacity in 24 hours have given a duty of 160,000,000 foot-pounds per 1,000 pounds of steam used by the engine. Centrifugal and rotary pumps have a duty depending on the type of engine used to drive them, and since they usually run at high speed, an economical type of engine can be used and the duty of the combined unit thus made to compare very favorably with that of the reciprocating pump.

1129. **Under what conditions is it best to make tests of the duty of pumps and pumping engines?**

Tests of the duty of pumps and pumping engines are generally made when the machinery is in first-class condition. It is customary to run these machines from 6 months to 1 year after they are installed before making the test, the object being to bring all the journals into a good bearing condition; the piston and all the other rubbing surfaces will also be much improved by the polishing and the working of oil into the pores of the iron during the running.

1130. **What is meant by the efficiency of a pump?**

When the efficiency of a pump is spoken of, its **mechanical** efficiency is generally meant, unless stated otherwise.

1131. **How can the efficiency of a pump be found?**

Divide the actual or net horsepower of the machine by its indicated horsepower, and multiply the quotient by 100. The efficiency will be expressed in per cent.

1132. **What are the average efficiencies of the various types of pumps?**

Very small direct-acting steam pumps have an efficiency of about 50 per cent., the efficiency increasing with the size of the pump up to about 80 per cent. Large vertical municipal pumping engines have shown an efficiency as high as 96 per cent.; horizontal medium-size crank-and-flywheel pumps show efficiencies as high as 90 per cent. The efficiency of a centrifugal, rotary, or screw pump varies between about 40 and 76 per cent., depending on the size. Small pumps are less efficient than large ones. This efficiency of centritugal, rotary, and screw pumps is the efficiency of the pump itself, and not the combined efficiency of the pump and engine, or motor, driving it.

1133. **Why does the efficiency of a pump increase with the size of the pump?**

The efficiency of a pump increases with the size of the pump by reason of the fact that the frictional resistances are decreased as the size of the pipes and passages is increased. The reason that the frictional resistances decrease can readily be seen when it is considered that by doubling the diameter of a pump and keeping the velocity of flow the same, the discharge will be increased four times, while the surface that the water is rubbing against is only doubled.

1134. **What should be the velocity of the flow of water in the suction and delivery pipes of pumps?**

For satisfactory work the velocity of water in the suction pipes of pumps should not exceed 200 feet per minute, and it should not be more than 500 feet in the delivery pipe for a duplex double-acting pump, or 400 feet for a single-cylinder double-acting pump.

1135. **Give a rule for finding the area of a pipe in square inches to discharge a given volume of water per minute.**

Multiply the volume of water in cubic feet by 144 and divide the product by the allowable velocity in feet per minute. When the weight of the water is given in pounds, divide it by 62.5 to reduce it to cubic feet; when the volume is given in U. S. standard gallons, divide it by 7.48 to reduce it to cubic feet.

1136. **Give a rule for finding the velocity with which water will flow through the delivery pipe of a pump when the area of the water cylinder, the area of the delivery pipe, and the piston speed of the pump are known.**

Multiply the area of the water piston by the piston speed and divide this product by the area of the delivery pipe.

1137. **For what kind of service are reciprocating pumps usually selected?**

The various types of **reciprocating** pumps are selected when high efficiency is required and a fluid for which they are adapted is to be used.

1138. **For what kind of service are the rotary pumps usually chosen?**

The **rotary** pump may be chosen when the water to be pumped holds in suspension large masses of soft material. It is much used in paper mills for pumping the pulp from one stage of its manufacture to another. Rotary pumps are small and occupy but little space for their capacity; they are also light, simple, and inexpensive, but are low in efficiency, and are short lived, particularly if the material pumped contains much sand or other grit. The rotary pump is used with good success on some steam fire-engines, where light weight and simplicity are more important than high efficiency.

1139. **For what kind of service are centrifugal pumps selected?**

Centrifugal pumps are usually selected where large volumes of water are to be lifted to moderate heights. They are well adapted for pumping large quantities of dirty water, and, therefore, are much used for dredging and for sewage pumping.

1140. **Explain some of the advantages and disadvantages of the centrifugal pump.**

The efficiency of the old-fashioned centrifugal pump is low, but it is extremely simple and occupies comparatively little space for its capacity. Like the rotary pump, it has no valves and the flow is continuous. It is less affected by sand and grit than is the rotary pump. Like the rotary pump, it requires very little, if any, foundation. Modern centrifugal pumps of the turbine or volute type are highly efficient, are adapted (in multi-stage forms) to high pressures, and may be driven by engines or motors which are much more efficient than the steam cylinder of a direct-acting pump.

1141. **For what kind of work are displacement pumps best adapted?**

Displacement pumps are best adapted for pumping all kinds of gritty water and are used for sinking and contractor's purposes. They are very simple in construction, low in first cost, and are not liable to get out of order, having no running parts. The class of pumps known as air lifts are principally used for artesian-well service; they require an air compressor for operation, but the apparatus itself is simple and low in first cost.

1142. For what kind of service are the screw pumps best adapted?

Screw pumps are best adapted for the handling of thick liquids, such as hot tar, pitch, paraffin, soap, etc. They have a uniform discharge and occupy small space; they are considered to be of a much higher efficiency than the rotary or centrifugal pumps.

1143. How may reciprocating pumps be classified?

Reciprocating pumps may be classified in accordance with the service for which they are intended as **boiler-feed** pumps, **general-service** pumps, **tank** or **light-service** pumps, **fire** pumps, **low steam-pressure** pumps, **mine** pumps, **sinking** pumps, **ballast** pumps, **wrecking** pumps, **deep-well** pumps, **sewage** pumps, **vacuum** pumps, **power** pumps, **municipal pumping engines,** etc.

1144. Briefly, describe the boiler feed pumps and their use.

For low pressures the boiler feed pumps are usually made of the piston pattern or the inside-packed plunger pattern. The cylinders are generally brass lined. The valves are brass or hard composition, with composition springs and guards, which features make the pumps suitable for handling hot water. For pressures above 135 pounds the outside-packed plunger type is preferred. Boiler feed pumps are made both vertical and horizontal and for pressures from 50 pounds to 300 pounds per square inch. They vary in size from those having water plungers 1 inch in diameter to those having plungers 10 inches in diameter. The single-cylinder type is much used for boiler feeding, but its action is not as satisfactory under all circumstances as that of the duplex pump.

1145. What is the objection to the use of steam-driven crank-and-flywheel pumps for boiler feeding?

The crank-and-flywheel pumps cannot always be run slowly enough to suit the demand without stopping on the centers.

1146. How fast should boiler feed pumps be required to run?

Boiler feed pumps should not be required to run faster than 100 feet per minute piston speed. The velocity of water through the suction pipe should not exceed 200 feet and through the delivery should not be more than 400 feet. If the pipes are long or fitted with elbows, the velocity should be correspondingly decreased.

1147. **In determining the proper size of a pump for boiler feeding, the pump is selected with reference to the amount of water required at the maximum capacity of the boilers. Give a rule for estimating the maximum water consumption in pounds per minute.**

For plain cylindrical boilers, multiply the product of the length and diameter in feet by .17. For tubular boilers, multiply the product of the square of the diameter in feet and the length in feet by .25. The maximum water consumption can also be estimated by multiplying the grate surface in square feet by 2, or by multiplying the estimated coal consumption in pounds per hour by .15.

1148. **Briefly describe the line of pumps known as general service pumps.**

They are pumps placed on the market by many of the pump builders intended to be used for any service where the water pressure does not exceed 150 pounds. They are generally of the plunger type and are built in sizes varying from those having a 4-inch to those having a 16-inch plunger, and of capacities varying from 100 gallons to 2,500 gallons per minute. They may be used for boiler feeding, fire, hydraulic elevators, etc.

1149. **Briefly describe the line of pumps known as tank or light-service pumps.**

They are of the same general form and interior construction as general-service pumps, except that the plungers are much larger in proportion to the steam cylinders, equaling or exceeding them in diameter. Such pumps cannot be used to feed their own boilers. They are commonly built of the same discharge capacity as general-service pumps, but can only pump against low pressures.

1150. Briefly describe the line of pumps known as fire pumps.

Fire pumps are most frequently of the duplex double-acting type, with a ratio of areas of steam cylinder and water piston of about 4 to 1. The duplex pump is chosen for this service on account of its simplicity and reliability and the peculiar adaptability of its motion to the high speed that is sometimes required in this service. A fire pump is frequently fitted up with a number of nozzles for hose connections. It has relief valves, air and vacuum chambers of large capacity, steam and water gauges, priming pipes, and all the necessary valves. Fire pumps are required to throw a large volume of water at high pressure.

1151. What are low-pressure steam pumps, and where are they used?

Low-pressure pumps are used in localities where only a low steam pressure is available. The ratio of areas of steam piston and water piston is about 9 to 1. Otherwise they are fitted up like pumps for general service. In some cases a hand power attachment is provided so that the pump can be worked by hand when the steam pressure is down.

1152. Briefly describe pressure pumps and their use.

Pressure pumps are invariably of the outside-packed type and generally have four single-acting plungers working in the ends of the water cylinders, the latter having a central partition. The water valves are contained in small separate chambers capable of resisting very heavy pressures and ingeniously arranged for ready access. All material used in the construction of the water end must be first class and suitable to the pressure used, which ranges from 750 pounds to 1,500 pounds per square inch. The water ends of these pumps are frequently made of hard, close-grained composition for medium pressures, and of steel castings for the heavier pressures. These pumps are designed especially for use in connection with hydraulic lifts, cranes, cotton presses, testing machines, hydraulic presses, oil pipe lines, mining purposes, and such services as require the delivery of liquids under very heavy pressure.

1153. Why does the reciprocating mine pump require more experience and skill to select than any other class of pump?

The reasons are the wide variations in conditions of service, conditions of operation, head or pressure to be worked against, and the destructive nature of the water to be pumped.

1154. Briefly describe a modern high-pressure mine pump.

The water end of the modern high-pressure mine pump may be described as having outside-packed plungers; strong circular valve pots independent of one another, but bolted to the working chamber, to the suction and delivery pipes, and to one another. Frequently the whole inside of the water end of the pump, from the suction nozzle to the discharge flange, is lined with wood, lead, or some other acid-resisting substance. Sometimes the entire water end is made of an acid-resisting bronze. The valves should preferably be metallic valves in separate pots or chambers. Simple, compound, or triple expansion pumps are used, depending much on the price of fuel.

1155. Where the cost of fuel is high, what class of pumps is used for mine work?

Compound crank-and-flywheel high-duty pumps using steam expansively have been installed in the coal mines; in the iron and copper mines, where the cost of fuel is very high, the highest types of pumping engines have been installed. The mine workings are generally so arranged that all the water runs to one large basin or sump near which a chamber of sufficient size is cut to contain the pump, which is protected by suitable devices to maintain it in a high state of efficiency.

1156. Give a general description of ballast and wrecking pumps, and the purpose for which they are used.

These pumps are principally confined to the marine service. The ballast pump is used on steamers having an extensive system of water ballast; also, for handling petroleum in bulk on oil-tank steamers. The wrecking pump has a somewhat wider sphere. It is used principally by wrecking companies on the Atlantic and Pacific coasts and along the Lakes and is constructed with particular reference to reliability, portability, and general efficiency. It has no forcing power, the water being merely delivered over the top of the pump, and it is single-acting, the water piston being fitted with valves. It is a very light form of pump in proportion to the work it will do, is simple, durable, and not liable to derangement or breakage. It is also well adapted to drainage and for irrigating purposes.

1157. **Give a general description of deep-well pumps.**

There is little choice in the selection of deep-well pumps except in the pump-driving mechanism, which is as varied as the agent available to drive it, the principal agents being steam, electricity, gas, and windmills. The pump is usually a lifting pump, having a bucket packed with numerous hydraulic leathers and working within the casing; it is usually given a very long stroke. These pumps do not handle gritty water successfully. Probably the best practical solution of the deep-well pump problem will be found in the air lift, which in principle and operation is quite simple.

1158. **Give a general description of the line of pumps known as sewage pumps.**

Sewage pumps are built in various types. The selection of a type of sewage pump will depend much on the capacity of the installation and the price of fuel delivered at the station. The principal peculiarities of the sewage pump are in the valves, which must be provided with very large ports to allow fairly large objects to pass through the pump without obstructing its valves. The valves are frequently made in the form of large leather-faced doors or flap valves, giving nearly the full area of the pipe. The sewage pump does not differ in other respects from pumps for general service.

1159. **Give a general description of the line of pumps known as power pumps, and their use.**

Power pumps are among the oldest styles of pumps, and may be developed by driving any type of reciprocating pump by other means than by the use of a directly attached steam, gas, or air cylinder. Power pumps are very often geared or belted. Power pumps may be used for any service and are frequently found in municipal water works, being often driven by a turbine or a Pelton waterwheel. In large electric-lighting, heat, and power plants, the power pump is much used for boiler feeding; in this case the pumps are usually triplex, giving a steady flow of water, and are driven by electric motors, the current being furnished by the main generators. This is probably the most efficient and economical boiler feeder that has been developed. The power pump is used quite extensively in mines. Many various sized pumps are placed at the different sumps throughout the mines and driven by one large and economical generating unit at the surface. The construction of the water end of a power pump does not differ from other pump constructions for the same service.

1160. What is meant by the term municipal pumping engine?

While the municipal pumping engine may be of any size and capacity, and while the general-service or power pump may be used, the term usually implies the highest type of pumping engine that can be constructed with respect to economy and efficiency.

1161. Mention some of the types of engines used in connection with municipal pumping engine installations.

For small municipal pumping engines, say of 2,000,000 to 5,000,000 gallons capacity in 24 hours, the compound and triple-expansion direct-acting engine is used, the degree of expansion depending on the price of fuel and the capital available for the investment. For installations of from 5,000,000 to 20,000,000 gallons' capacity, the direct-acting engine with high-duty attachment, and the crank-and-flywheel engine are used. For large municipal pumping engines above 20,000,000 gallons capacity in 24 hours, the vertical triple-expansion condensing three-crank single-acting, or differential, plunger-beam type may be said to have no equal.

With the last type of engine a duty of 160,000,000 foot-pounds of work per 1,000 pounds of steam used by the engine is now common, while the number of expansions is as high as 22 to 26.

1162. What is a vacuum pump and what is its use?

A vacuum pump is in reality an air pump, it being used for pumping air out of closed vessels. There are two general types of vacuum pump, **dry vacuum pumps** or pumps that handle air only, and **wet vacuum pumps,** or pumps that handle both air and water. Vacuum pumps are chiefly used in connection with jet condensers and siphon condensers. They are also used in some manufacturing operations where a high degree of vacuum is required, as for instance, in connection with the vacuum pans found in sugar houses, glycerin factories, etc.

1163. Mention some of the relative merits of the direct-acting and crank-and-flywheel pumps.

For pumping small quantities of water, say up to 700 gallons per minute, and in localities where coal is not expensive, the direct-acting pump should prove a good investment. The objection to the direct-acting pump for large sizes is its waste of steam as compared with the crank-and-flywheel pump. The crank-and-flywheel engine is more expensive than the direct-acting machine, and when high degrees of expansion are used occupies more room. It is generally more complicated, but is more accessible, except in cases where an effort is made to minimize space. The piston speed of direct-acting pumps rarely exceeds 100 feet per minute, while the piston speed of crank-and-flywheel pumps is commonly 300 feet and sometimes 400 feet. With pumps of the controlled-valve type, piston speeds of 560 feet are reached. The crank pump is sure in its action and is not liable to get out of order, which cannot be claimed for some of the single-cylinder direct-acting pumps having steam-thrown valves. The crank pump is limited as to its slowest speed, however, since the speed must be sufficient to store energy enough in the flywheel to carry the crank over the dead centers.

1164. Mention a method used for securing an increased degree of expansion in compound and triple-expansion direct-acting pumps.

By making the reciprocating parts heavy and running the pump at some fixed minimum speed, an early cut-off can be effected in the high-pressure cylinder, the balance of the stroke being completed by the inertia of the reciprocating parts; in this way an increased degree of expansion is secured.

1165. What is, probably, the most objectionable feature of the crank-and-flywheel pump?

It is the fact that the velocity of discharge varies throughout the stroke. This is due to the fact that while the flywheel rotates at a uniform speed, the pistons and plungers move with a variable speed, varying from zero at the beginning of the stroke to the maximum speed near mid-stroke and then decreasing to zero at the end of the stroke. This variation in velocity produces shocks, and therefore requires the water end of a flywheel pump to be of heavier construction than the water end of a direct-acting pump.

1166. Why is it necessary to have the valve area of a flywheel pump larger than for a direct-acting pump?

This is necessary not only because the flywheel pump has a capacity for higher speeds, but also because the velocity of the plunger, when the connecting-rod is at right angles to the crank arm, is somewhat in excess of 1.57 times the mean velocity of the plunger.

1167. What are the main advantages of the crank-and-flywheel pump?

Its main advantage is its economy, which is due to the fact that the steam may be expanded to any desirable degree; it also readily admits of all the refinements known for securing high-duty performance, and with a proper arrangement of details, it can be made quite as safe as ordinary machines.

STEAM HEATING

1168. Define a steam main.

A **steam main** is the pipe that conveys steam from the boiler or other source of supply and distributes it to the several branches.

1169. Explain briefly how a steam main is usually run.

It is usually run along the cellar ceiling, being hung from the first-floor beams by adjustable iron hangers. It pitches down from its highest point near the boiler to its lowest point at the farther end of the main. The **pitch** should be at least ½ inch in 10 feet, so that the water of condensation may flow freely to the lower end of the main.

1170. Why should steam mains pitch down and away from the boiler, and return mains down and toward the boiler?

This should be done so as to have the water and steam run in the same direction through the pipes and thereby to prevent noise in the system.

1171. What is an (a) overhead main, (b) a rising main?

(a) An **overhead main** is a steam main that is run horizontally, or nearly so, at an elevation higher than the radiators. (b) This overhead main is supplied from the boiler by a vertical **rising main.**

1172. What are (a) risers, (b) drop risers?

(a) **Risers** are the vertical pipes that convey steam from the steam main to the radiators or coils on the several floors. (b) **Drop risers** are those in which the steam flows downward to the radiators or coils from a steam main above.

1173. What are riser connections?

Riser connections are the pipes, usually short and nearly horizontal, that connect the steam main to the lower ends of the risers, or an overhead main to the upper ends of the drop risers.

1174. What is meant by the term riser lines?
The steam and return risers taken together.

1175. What are radiator connections?
They are the pipes that connect the radiators to the risers or mains; they are usually no longer than is necessary to get sufficient spring for the expansion of the risers and seldom larger than 2-inch pipe.

1176. What is a return main?
It is a nearly horizontal line of pipe, usually run near or under the cellar floor; it receives all water of condensation from the heating system and returns it to the boiler or otherwise disposes of it.

1177. What are return risers?
Return risers are those vertical pipes that take the water of condensation from the radiators or coils on the several floors of a building and convey it to the return main.

1178. What is a drip pipe, relief, or bleeder?
A **drip pipe, relief,** or **bleeder** is a small pipe used to drain water of condensation away from a low point (called a **pocket,** or a **trap**) in the steam pipes.

1179. What is meant by the term the steam-riser relief?
The pipe which connects the bottom of the steam riser with a Tee in the bottom of the return riser or with the main return pipe, generally below the water-line.

1180. What is meant by the term main relief pipes?
Connections between the main steam and return pipes, to throw the water carried from the boiler, and that condensed in the main steam-pipe, into the return main, and also employed to equalize the pressures in the system.

1181. What is a dry return main?
A **dry return main** is one that is run above the water-line of the boiler and is consequently partly filled with steam.

1182. What is a wet return main?
It is one that is run below the water-line and is filled with water at all times.

1183. Which is more reliable, the dry or the wet return main?

As a rule, the wet return main is more reliable than the dry return main except in places where the main is subject to frost.

1184. What are steam coils?

Coils consist of a number of pipes stacked together for the purpose of giving off heat to the air around them.

1185. What is direct radiation?

Direct radiation is a term applied to all kinds of coils and radiators that are placed inside the rooms to be heated.

1186. What is indirect radiation?

Indirect radiation is a term applied to all kinds of coils, radiators, and other forms of heating surfaces that are located outside the rooms to be warmed.

1187. Where and how are indirect radiators usually placed?

They are usually hung from the cellar ceiling, are encased with a galvanized sheet-iron jacket, and are so constructed that fresh air from the outer atmosphere flows over and between the heating surfaces and then enters the room, thus providing ventilation as well as heat.

1188. What is direct-indirect radiation?

Direct-indirect radiation, sometimes called **semi-direct,** is a term applied to all kinds of radiators and coils that are located in the rooms to be warmed and are provided with means for fresh air to enter through them to the rooms from the outer atmosphere.

1189. Classify, in a general way, the various systems of heating by steam.

The various systems of heating by steam may be classified as **high-pressure systems,** or systems of heating that work on a pressure greater than 10 pounds by the gauge; **low-pressure systems,** or those that work between atmospheric pressure and 10 pounds by the gauge; and **vacuum,** or **exhaust, systems,** which include all systems that work at a pressure sometimes lower than that of the atmosphere. Any one of these systems may be subdivided into: **The one-pipe system; the two-pipe system; the two-pipe system with separate return risers**; and the **overhead-main, or drop-supply system.** These, in turn, may be **gravity-return** or **forced-return systems,** and they may have **wet return** or **dry return mains.**

1190. Explain how the water of condensation is returned to the boiler in the gravity-return system, and in the forced-return system.

In the **gravity-return system,** the water of condensation flows back to the boiler by gravity, the full boiler pressure being allowed on the heating system. In the **forced-return system,** the water of condensation is forced back to the boiler by a pump, steam loop, steam-return trap, or other such contrivance. In this system, the boiler pressure is higher than the pressure in the heating system, and a **pressure-reducing valve** is used on the steam-supply pipe to the heating system.

1191. Briefly explain the one-pipe system of heating.

In the **one-pipe system,** steam flows from the boiler through a riser and is conveyed to the radiators through suitable branches, which are nearly horizontal. All the water of condensation flows backward through the same pipes, moving in a contrary direction to the steam. All the nearly horizontal pipes are inclined sufficiently to secure the ready movement of the returning water. The **one-pipe** system can be used only on small jobs.

1192. Briefly explain the two-pipe system of heating.

In the **two-pipe system,** each radiator has two connections; one is an inlet for steam and the other an outlet for water. The branch, or radiator connection, that supplies steam to the radiator, is inclined so that the water formed within it will flow toward the radiator. If the radiator is at a considerable distance from the riser, the radiator connection is connected to the return pipe by a small relief pipe, so that the water will be drained off and prevented from entering the radiator. If the steam main is of any considerable length, it is also inclined so that the water formed within it will run toward the foot of the riser. All the water formed in the main and riser is also drained off by a relief pipe connected to the return pipe so that the steam and the water are carefully separated at all points in the system.

1193. **What is the difference between the two-pipe system, and the two-pipe separate-return system?**

The difference is in the returns, each radiator in a separate-return system being provided with its own separate return pipe. In other respects the two systems are the same.

1194. **Briefly explain the drop supply system of heating.**

In this system of heating, the steam supply passes up a riser to the top of the system, then along a horizontal pipe, and descends through a return or drop pipe back to the boiler. The radiators are connected to the drop pipe with single pipes, the same as in a one-pipe system. In this system, the water in the pipes moves in the same direction as the steam, instead of in the opposite direction, as in the one-pipe system. It is always advisable to make the returns as direct as practicable, but they may follow any convenient route back to the boiler.

1195. **What are some of the defects of the one-pipe system of heating?**

The circulation is not quite as certain as in the **two-pipe systems,** and a radiator at the end of a long horizontal branch is liable to have its steam supply interrupted by the assembling of drops of the returning water into **slugs,** filling the bore of the pipe and causing **water hammer.** The steam and water flow in the same pipe, and the steam is always likely to be wet. On account of the large amount of mechanical interference between the steam and the water, which flow in contrary directions, larger pipes are required than would otherwise be necessary, and there is also much greater liability to water hammer and to sizzling noises. When the steam valve to a radiator remains nearly closed for a considerable time, but not shut tight, the radiator will gradually fill up with water.

As soon as the valve is opened, a violent struggle will begin between the entering steam and the escaping water, and a succession of rumbling, hammering, and snapping noises, which will continue for several minutes, will be the result. In a large **one-pipe** heating system, the amount of water to be returned to the boiler is so great that it becomes very difficult to pass it through the steam supply without interfering with the flow of steam to the radiators.

1196. Explain why it is advisable to divide large heating systems into several independent sections, and how it is accomplished.

By dividing a large heating system into sections, long or troublesome horizontal branches may be reduced to a minimum. Independent risers are located where they will supply the largest number of radiators to the best advantage. The question of the number of risers to be used will be determined mainly by considering the drainage in the horizontal pipes. In all cases it is advisable to have the horizontal branches as short as possible. Each section of a heating system should be made independent of the others, so that it can be closed down for repairs without affecting any other part of the system. Large straightway or gate valves should be placed close to the mains in both the supply and return riser connections.

1197. When globe or angle valves are used in the supply and return connections in a heating system, why should the valves be turned with the pressure side toward the boiler?

When the valves in a heating system are turned with the pressure side (the under side of the disk) toward the boiler, the stuffing-box or gland of any valve can be removed without the escape of steam by simply closing the valve to be packed and its corresponding valve in the return, or vice versa, and waiting for the steam to cool down.

1198. What precautions must be taken in designing pipe systems for heating, and why?

Precaution should be taken to provide for **drainage,** and for the movement of the pipes by **expansion** and

contraction because no heating can be done without condensation, and because expansion or contraction are inevitable every time the system undergoes any considerable change in temperature.

1199. If a main or any horizontal steam supply pipe is too long to be given a uniform grade for drainage purposes, how can it be drained?

In such a case **vertical offsets,** or **relays,** are introduced in the line of pipe, and a relief pipe is attached at the foot of each offset.

1200. Explain why a long riser should not be connected directly into the top of the steam main by a Tee?

If the riser is long, its weight will cause the main to sag and if the connections to the radiators above are rigid, the downward expansion will either bend the pipe or lift the radiators.

1201. What precautions should be taken in connecting up the return pipes?

The downward grade given to return pipes should be as nearly uniform as practicable. There should be no upward bends or loops, because air is likely to collect in them and impede the flow of the water. Sags or depressions in which water will accumulate should also be avoided.

1202. What is the objection to a dry return main or a main located above the water level?

When the returns are connected to a main that is located above the water level, if there is any difference in the pressures at the various radiators thus connected, the steam will flow backward through the return pipes toward the points of lowest pressure, and in most cases will spoil the drainage and cause water hammer.

1203. What is the advantage of a wet return main?

When a return main is located below the water level, the water that it contains prevents the passage of steam from one return to another. The steam is compelled to pass through the system in the direction it was intended to go, instead of making a short circuit or by-pass. This makes a positive circulating job.

1204. What can you say as to the water level in returns?

There is always more or less difference in the pressure of the steam in the boiler and at the end of a line where the return is connected; therefore, the water will rise in the return to a height above the water level in the boiler sufficient to balance the difference in pressure. As this difference varies in the several returns, the water is likely to stand at different heights in them. The hot water rises about 29 inches for each pound of difference in pressure. If there is a water pocket anywhere in the return pipe, the water will back from it toward the radiator until it balances the difference in pressure upon the opposite sides of the water. That is why a radiator that is well above the proper water-line may be flooded with back water if there is a water pocket near it in the return.

1205. What do you consider to be the proper size of pipe for branches for radiators?

The proper size of pipe is one that will furnish a sufficient amount of steam without undue fall of pressure, and at the same time will not present an unnecessary amount of surface for condensation.

1206. State a rule for computing the size of steam mains or of principal risers.

Divide the amount of direct heating surface in square feet by 100; divide the quotient by .7854; then extract the square root of the quotient; the result will be the diameter of the pipe in inches.

1207. When a globe-valve is used as a stop-valve in a steam main, why should it be turned with its stem nearly horizontal instead of up?

When a globe-valve is turned with its stem up, the water in the pipe has to half fill it before it flows over the valve seat to pass along in the pipe. But, when the valve is on its side, the side of the opening of the valve seat is as low as the bottom of the pipe and the water will flow along freely.

1208. When a valve is placed on its side, why should the stem of the valve be raised a little above the horizontal position?

The stem of a valve placed on its side should be raised about 10 degrees to prevent water from collecting in the threads of the nut and stem, and being forced out by the pressure of the steam through the stuffing-box, which makes a leak that is almost impossible to stop with ordinary packing.

1209. State a rule for finding the amount of radiator surface that may be properly supplied by any given size of pipe.

Multiply the square of the diameter of the pipe in inches by .7854; then multiply the result by 100; the result is the total amount of heating surface in square feet which the pipe will supply.

1210. About how much do the iron pipes used for steam fitting expand, and what are the effects ot such expansion?

The pipes used for steam fitting expand about 1½ inches per hundred feet in length for usual changes in temperature. If this expansion is not provided for in long lines of pipe, it will make trouble by breaking connections or shoving apparatus out of place.

1211. How is the expansion in long steam lines taken up?

In large pipes the expansion may be taken up by means of an ordinary **expansion sliding joint.** The sliding tube of the joint is made of brass or bronze to prevent its corroding and sticking fast. Generally, these sliding joints are objectionable because of the care required to keep the packing tight and in good order. In the smaller sizes of pipes, an offset is made in the pipe, and the piece forming the offset, which is called the **spring piece,** is made long enough to bend or spring sufficiently to permit the necessary movement of the pipes without straining the threads or cracking the fittings. The spring piece is sometimes bent into a **loop,** but pipes of this kind are usually made of copper, with brass flanges brazed on. The spring piece is also bent into a **coil.** This form of spring piece is made out of ordinary wrought-iron pipe without difficulty. To prevent forming a pocket, the loop or coil is extended horizontally instead of vertically.

1212. What consideration should be given the matter of expansion, during the erection of a steam-heating plant?

The best point for fastening each principal pipe so that its expansion will cause the least disturbance should be carefully determined. Care must be taken to have every such pipe **free** at its ends and to see that its connections or branches are not bound or made immovable by plaster, brick, wood, or iron beams or columns. All these points should be carefully inspected to make sure that the entire pipe system is **free to expand** before steam is turned on.

1213. Briefly explain the method of procedure in piping a building.

New buildings are piped while the work of construction proceeds, as soon as the walls are up and the roof is on. On large jobs the risers are usually put up first, next the horizontal branches are constructed, proceeding always from the riser toward the radiators, and lastly the mains are put in place. The returns are constructed at the same time and in a similar manner. In many cases, however, particularly in small buildings, the mains are run in first, then the risers, and finally the riser connections. This latter method avoids the use of **right and left** fittings, or unions, between the risers and the mains. All radiator connections should be promptly **capped** as soon as erected, and all openings in Tees and other fittings should be **plugged** at once, so that no dirt may get into the pipes.

1214. Why should the piping for a heating system be tested before it is covered up by plaster or flooring?

Because defective fittings or split pipes can be easily discovered and replaced without trouble.

1215. In what two ways should a system of piping be tested?

A system of piping should be tested by filling the system full of water, every opening being tightly closed, and then applying pressure by means of a force pump. The pressure should be increased until the gauge shows 100 to 150 pounds per square inch. Another test should be made with steam, to determine whether the expansion is properly provided for and whether the system is in working order. The steam pressure used for testing should not greatly exceed the proposed working pressure.

1216. What precaution should be taken regarding the contact of steam-supply and return pipes with woodwork or other combustible material?

A clearance of at least 2 inches should be maintained at all points, and where this cannot be had, special protection should be provided.

1217. Is there any saving effected by the use of exhaust steam for heating?

Yes. Exhaust steam at 5 pounds gauge pressure contains, if dry, about 970 British thermal units per pound that are available for heating and that would be discharged through the exhaust pipe into the atmosphere, if not used.

1218. Briefly explain the general arrangement of apparatus for controlling the steam supply and drainage in an exhaust heating system.

The steam-heating main is connected to the exhaust pipe and also to a pipe that supplies live steam from the boilers. This live steam passes through a pressure-reducing valve and is lowered in pressure to the desired amount before entering the heating main. If for any reason the supply of exhaust steam becomes insufficient to maintain the proper pressure, the live steam will automatically enter through the reducing valve and make up the deficiency. If the supply of exhaust steam becomes excessive, so that the pressure rises above that desired, the excess will escape by opening the back-pressure valve and blowing into the atmosphere. When the engines are stopped, the steam in the heating apparatus is prevented from passing backward and filling them with water by means of a check-valve. The back-pressure or relief valve fitted in the exhaust pipe is usually adjusted to blow off at a pressure about 1 pound higher than that maintained by the reducing valve. The exhaust steam is passed through a separator before entering the heating system, for the purpose of removing the oil and water that accompany it from the engines. The drainage from the heating apparatus is returned to the boiler by means of a pump. The returns have no direct connection with the boiler, therefore the water level in them may be maintained at any convenient height. This is accomplished by means of the pump and its governor.

1219. **Describe a pump governor and its action.**

A **pump governor** is merely a closed vessel containing a float that rises and falls with the water level. The steam that drives the pump is taken from the high-pressure line through a stop-valve and passes through a throttle valve that is controlled by the float. When the water rises above the desired level, the float opens the throttle and starts the pump; when the water drops, the float is lowered and shuts off the steam. The pump governor is connected to the heating main by a small pipe for the purpose of equalizing the pressure on top of the water therein.

1220. **Give a general description of the vacuum system of steam heating, and state in what way it differs from all other systems.**

The **vacuum system** of steam heating differs from all others in one particular, which is, that a more or less perfect vacuum is generally maintained in the returns. This permits the system to be operated with either high or low pressure steam, and from any source, either exhaust or otherwise. The pressure and temperature throughout the whole system may be adjusted and maintained at any degree between full-boiler pressure and a low vacuum, thus making the system adjustable to suit all conditions of weather and service. The piping is usually arranged on the two-pipe system, and the returns are generally made independent, although it is not necessary to do so in all cases.

1221. **Mention some of the most essential features of the vacuum system.**

The returns are connected to a receiver, which collects all the air and water in the system. These are pumped out by means of a **vacuum pump**, which thus maintains a vacuum of any degree desired in the returns. By this arrangement any steam may be used in the radiators that is warm enough to operate the traps or **thermostatic valves** that are placed on the return end of each radiator to open automatically when water or air is required to pass through, but to close when steam begins to pass through. This prevents the returns from becoming filled with steam. The vacuum system permits steam to be used at a pressure far below that of the atmosphere and at any temperature down to about 140°, the limit being fixed only by the ability of the pump to keep up the vacuum in the returns. The water and air that are drawn from the receiver by the vacuum pump are discharged into an open tank from which the air readily escapes. The water is then pumped back into the boiler by any ordinary feed-pump.

1222. **What is the advantage and disadvantage of injecting into the receiver of a vacuum heating system the cold water required to feed the boilers?**

In some cases the cold water is injected into the receiver in a series of fine streams, the object being to condense as much as possible of the steam that may be present and thus to improve the vacuum. But the disadvantage is that at the same time that the water becomes warmed it gives up the air accompanying it, thus increasing the amount to be removed by the pump. This air expands into the vacuum and partially neutralizes the effect of the condensation.

1223. **Mention some of the advantages of the vacuum system of steam heating.**

When the exhaust steam from an engine is turned into the ordinary low-pressure heating system, the back pressure is increased, and the efficiency of the engine is correspondingly decreased. In the vacuum system, a great part of the back pressure is taken off the engine, and the capacity of the engine to do useful work is thereby increased. The size of the piping required for the vacuum system is about the same as for an ordinary low-pressure system. The volume of the steam required is greater, owing to the low pressure, and the amount of heat per cubic foot is correspondingly less than that found in ordinary heating systems, but the difference between the pressures of the steam in the supply pipes and in the returns is so great that the volume of steam necessary to carry the amount of heat required is driven through the pipes without difficulty. The radiators, however, must be somewhat larger than for any other system, in proportion as the temperature of the steam used is lower. One great advantage of the vacuum system is its ability to furnish **moderate** heat. An ordinary system **must** circulate steam at 212° or a higher temperature, if it circulates at all. The only way to check the heat is to shut it off entirely. With a vacuum system, the supply of heat when the steam is at 140° is just half what it is when the steam is 210°.

1224. Briefly explain the district system of heating.

The **district system** of steam heating is used in some large cities. The steam mains, from the district station, are laid underground through the streets. The service pipe is provided with a valve inside the basement wall, through which it enters the building, so that the house system can be shut off when desired. The steam passes through a pressure-reducing valve and thence into the distributing pipe or house main. The water that may enter from the service pipe is led away by a drain. The returns are all connected to a pipe, which is submerged below the water level. The level of the water in the returns is fixed by the elevation given the steam trap. The hot water from the trap should never be discharged directly into the house drains, because of its destructive effect upon the pipes, but should be cooled before escaping to the sewers, by first allowing it to flow through a coil of pipes, usually called a **cooling coil.** This coil should in all cases deliver into a deep, sealed trap, and not directly into the drainage system. This is to prevent drain air from entering the heating system or the building. The trap, or **hotwell,** should always deliver into the **house—sewer** connection on the sewer side of the main—drain trap, to prevent hot vapors from passing up the iron pipe drainage system in the building.

1225. Briefly explain how automatic air vents on steam-heating systems operate.

Automatic air vents on steam-heating systems are **thermostatic** in principle; that is, they are controlled by a difference in temperature between the steam and the air that is to be expelled from the heating apparatus. The valve is a rod composed of some expansible material that is adjusted against a small opening, called the **steam orifice**, by means of a screw. When air enters the steam orifice, the rod cools and shortens slightly, thus opening the orifice and permitting the air to flow through. As soon as hot steam arrives, the rod expands and again closes the vent.

1226. What is the objection to automatic air vents that are thermostatic in principle, and how is this objection remedied?

Automatic air vents that are **thermostatic** in principle permit the escape of water as readily as air, and therefore must be provided with suitable drip pipes. Otherwise, they are liable to discharge water at almost any time and to make serious trouble. This trouble is remedied by attaching a cup or float to the stem of the air valve. This stem rests loosely on a bent spring, and when the chamber fills with water, the float will lift the valve and close the vent. The valve is opened to discharge air by the bending of the spring, which is made of two strips of different metals firmly soldered together. These contract by different amounts when cooled, thus bending the spring and allowing the valve to open slightly.

1227. Where should an air vent be placed on a radiator with reference to the steam inlet?

The air vent should be attached to a radiator or coil at a point as far as practicable from the steam inlet, so as to prevent the current that moves toward the vent from carrying hot steam to it and thus closing it before all the air has escaped.

1228. What is meant by plain heating surfaces, and extended heating surfaces of radiators and coils?

Heating surfaces of radiators and coils that have no projections of any kind are classified as **plain surfaces**;

those having ribs, knobs, pins, or other projecting parts are called **extended surfaces.**

1229. **What is the object sought in the construction of extended surfaces of radiators and coils?**

The object sought is to increase the area of the heat emitting surface.

1230. **Explain under what conditions the different heating surfaces of radiators and coils are most effective.**

When a radiator stands in still air, the plain surfaces clear themselves of hot air better than do the extended surfaces; and are, therefore, more effective. Extended surfaces have an advantage over plain surfaces only when the velocity of the air passing over them is sufficient to sweep them clean of hot air as rapidly as it is formed.

1231. **Explain how the efficiency of a radiator or coil can be increased.**

The efficiency of a radiator will increase as the velocity of air passing over it is increased, but not in the same proportion. With increased velocity, the duration of contact of air with the hot surfaces is shortened and the rise of air temperature will be less, but the quantity of air heated will be increased so much, that the total heat given off from the radiator per square foot of surface per hour will be increased. The efficiency can also be increased by placing the coil or radiator in a horizontal position. Each tube will then operate throughout its whole length upon air of equally low temperature, and the rate of emission will be greater. If the radiator tubes are in a vertical position, the air, which is warmed at the lower ends of the tubes, flows upward and envelops the upper parts in a current of hot air. The emission of heat will be slower from the upper part of the tubes than from the lower part, because the difference in temperature between the air and metal is less.

1232. **Why is the radiator or coil having only a single row of tubes the most effective form for direct heating?**

If radiator tubes are grouped together in large numbers, the efficiency of the tubes in the interior of the group will be much less than that of the outside tubes, because the access of cold air to them is practically cut off, and they can act only on air that has already been warmed by the outer tubes. Their efficiency is still further reduced by the fact that nearly all the heat that they emit by radiation is cut off or blocked by the outer tubes.

1233. Describe the construction of flue radiators and the advantages of this construction.

Flue radiator tubes are so shaped that, when they are assembled in a group, they form vertical air flues. The bases of the tubes are set high enough above the floor to permit of an abundant flow of air into the flues at the bottom. The advantages of this construction are that the interior parts of the radiator are well supplied with air and that the flues impart a higher velocity to the air than it would otherwise obtain.

1234. Briefly describe the construction of a continuous flat coil.

It is made of straight pipe connected by return bands. The circulation of the steam through it is direct and certain, and it is regarded as the most efficent form of radiator in common use.

1235. Briefly describe the miter coil.

In the **miter coil** the pipes are connected between two manifolds. The steam moves forward through all the pipes at the same time; therefore, in an eight-pipe coil, for instance, the velocity of the steam will be one-eighth the rate in a single pipe. If the steam enters the end of a manifold, the circulation will be uneven, because the steam entering at one end of the manifold will naturally, owing to its momentum, flow to the other end of the manifold, and so a greater quantity will enter the pipe connected at that end. It is better to have the steam enter at a special bossed opening on the back of the manifold casting, opposite the openings to the pipes. The horizontal pipes in such coils are connected to the horizontal manifold by means of elbows and vertical pipes. This must always be done, so as to permit the several pipes to expand independently, as their varying temperatures may require.

1236. Briefly describe the manifold coil.

A **manifold** coil is one in which the two manifolds are connected by means of straight pipes. It is difficult to keep coils of this construction steam tight. The upper pipes expand more than the lower ones, and they will either bulge and spring, or they will crack or break some of the connections.

1237. What is known as a box coil?

When several **flat coils** are grouped together, the construction is called a **box coil.**

1238. What must be taken into consideration when determining the size of pipe for the construction of coils, and how should pipe coils be arranged with regard to condensation?

In determining the size of pipe for the construction of coils, the pressure of steam to be used, the length of the coil, and the force of the circulation through it, must be taken into consideration. A coil in which the current of steam is diffused throughout the whole series, could be made of smaller pipe than one in which the whole current of steam is passing through each pipe. The customary size of pipe used is from 1 inch to 1½ inches, the larger size being used for exhaust-steam heating. Pipe coils must be arranged so that all water that is condensed within them may flow easily toward their outlets.

1239. Describe the Nason tube used for the construction of radiators.

The **Nason tube** is connected to the radiator base by a single screw joint and is divided into two passages by means of a sheet-iron plate that extends nearly to the top of the tube. The steam rises on one side, passes over the end of the plate, and descends on the opposite side of the tube. Each tube thus forms a complete loop, or circuit.

1240. Describe the Bundy loop, used for the construction of radiators.

The **Bundy loop** is screwed into a cast-iron radiator base of suitable shape, and the steam moves up one branch of the tube and down the other.

1241. Describe the Detroit loop used for the construction of radiators.

Each **Detroit loop** is complete in itself and requires no base or supply chamber. The loops are connected together, in any number desired, by means of nipples at top and bottom. When the connection at the top is not desired, the loops are bound together by a bolt that passes through the space between them. These loops are often constructed with three or even four parallel tubes. They are also modified so as to form flue radiators.

1242. Describe the pin radiator.

It is an extended-surface indirect radiator, in extensive use for indirect heating. It is called a **pin radiator** because the extensions of the heating surface are made in the shape of small conical pins. The air flows up between the sections and impinges against the pins.

1243. Describe the forced-draft heater.

Forced draft heaters are commonly used for heating air on a large scale, where forced draft is used. The tubes are of 1-inch steel or wrought-iron pipe and are connected at the top by cross pipes instead of return bends, thus preventing all distortion by unequal expansion. The tubes are staggered, so that those in one row stand opposite the spaces between the tubes in the preceding row. By this means, all parts of the air-current, which passes through horizontally, are brought into contact with the tubes and thoroughly heated. The base sections, or headers, are coupled together at one end by flanged joints. The group of base sections may be divided into two or more parts, each of which may have an independent supply and return pipe. Thus, the whole heater may be used, or only a part of it, as desired. The sides of the sections are corrugated so that they interlock and leave no open spaces between them. The farther end of each section rests on a roller, so that sections can expand and contract freely without straining.

1244. Briefly explain how the ordinary, vertical-tube radiators are adapted to direct-indirect heating.

The base of the radiator is enclosed by plates, so that the fresh air which comes in through a tube, or opening in the wall, is compelled to pass upward and between the hot tubes before it can escape into the room.

1245. How would you determine the amount of radiation required to warm a given space?

Calculate the total outside, or cold glass surface in windows, doors, skylights, etc., in square feet. Take seven-tenths of the total and call it **G.** Then calculate the total outside, or cold wall surface in square feet (include floors and ceilings only when they are outside or cold). Take one-fifteenth of this and call it **W.** Add **G** and **W** to obtain the square feet of direct steam radiators necessary to maintain 70° Fahr. in zero weather with no special allowance for air leakage or ventilation. For indirect steam radiators, double the amount of surface, which is found to be necessary with direct radiators.

1246. What is the relation between the heating surface of the boilers and the radiating surface in the buildings to which they supply steam?

There is no simple relation between the two, since the class of boiler used, the amount of grate surface, the state in which the fires are kept, the fuel burned, the amount of heat lost in warming the air admitted for ventilation, etc., must be taken into consideration. One simple rule, however, can always be borne in mind—namely, that 1 square foot of average boiler surface will evaporate at least 2 pounds of water in an hour, and that between 7 and 8 square feet of radiation will condense the same amount of water in the same time under average conditions. Of course, power boilers can be forced to evaporate 3 or 4 pounds of water per square foot of heating surface, but this is not good practice in house heating boilers.

1247. Give the ratio of radiator surface to cubical contents of room to be warmed, commonly supplied for ordinary purposes.

Radiator surface in proportion to the cubical contents of the room to be warmed is commonly supplied as follows: For bathrooms and living rooms with three exposed walls and a large amount of glass surface, 1 square foot for each 40 cubic feet; for bathrooms and living rooms with two exposed walls and large amount of glass surface, 1 square foot for each 50 cubic feet; for bathrooms and living rooms with one exposed wall and an ordinary amount of glass surface, 1 square foot for each 60 cubic feet; for sleeping rooms, 1 square foot for each 60 to 70 cubic feet; for a hall, 1 square foot to each 50 to 70 cubic feet; for school rooms, 1 square foot to each 60 to 80 cubic feet; for churches and auditoriums having large cubical contents and high ceilings, 1 square foot to each 60 to 100 cubic feet; for lofts, workshops, and factories, 1 square foot for each 75 to 150 cubic feet is supplied. If indirect radiators are used, allow not less than 50 per cent. more surface. If direct-indirect radiators are used, allow not less than 25 per cent. more surface. In estimating radiation, ample allowance should be made for exposure of building, materials of construction, and loose doors and windows. To determine correctly the amount of radiation required properly to warm a given space requires the best judgment of a heating engineer.

1248. If a radiator, or coil, does not heat when the steam is turned on, what is usually the trouble?

If the radiator valves are open, the air valve is choked up or otherwise closed so that it will not let out the air.

1249. If a hammering or hissing noise is heard in a radiator, or coil, when the radiator valve is closed, what may be the trouble, and how should it be remedied?

The radiator valve is not tight and a new disk should be put on. This can be done by shutting off steam from the riser line to which the radiator or coil is connected. If the radiator is connected on the two-pipe system, the return riser must also be shut off to prevent steam and water from backing up into the radiator through the returns. The valve seat should be examined carefully. If a groove has been ground out or the valve face is rough, it is advisable to grind it or to face it smooth and true with a reseating tool.

1250. What attention should be given an ordinary heating system?

In the spring, when the system is put out of service for the summer, the return mains should all be drained clear, all valves should be examined and repaired, if necessary, and everything connected with the system should be made clean and ready for firing up at a moment's notice or for turning on steam from a power boiler or from the engine exhaust. As floors and walls are liable to settle, the steam-pipe hangers should be examined and adjusted, if necessary, so that the grades of the pipes may be adjusted to prevent water hammer. If a heating system receives proper attention during the summer, it should run all winter without repairs.

MECHANICAL STOKERS

1251. Explain the two general classes into which mechanical stokers and automatic furnaces may be divided.

The two general classes into which mechanical stokers and automatic furnaces may be divided are the **over feed** and the **under feed.** In the **over feed,** the coal is slowly fed, by some suitable mechanical device, on a coking plate, where the volatile matter is distilled off by the heat of the furnace and mixed with a suitable supply of air. The coke so formed is then fed forward on to grates, where it is burned. The mixture of gas and air is burned in a suitable combustion chamber, usually located as near to the bed of burning coke as is practicable. In the **under feed** type the coal is forced by some mechanical device from **under** the mass of burning fuel in the furnace. The volatile matter is distilled off and mixed with a supply of air. The coke formed is pushed upward by the fresh coal, and burns on suitable grates, on which it falls. The mixture of gas and air rises through the bed of burning coke and, being highly heated and thoroughly mixed, burns readily.

1252. What is one of the most important advantages of automatic stokers?

The coal is fed to the furnace at a uniform rate and in such a manner that the gases distilled from it are thoroughly mixed with a proper supply of air. When the coal supply and air supply are properly adjusted to suit the working conditions, the continuous and uniform manner in which the fuel is fed to the furnace insures a high and practically uniform temperature, which is favorable for the complete combustion of the gases and relieves the boiler from the stresses produced by sudden changes in temperature that occur when cold air enters the fire door during hand firing.

1253. Compare hand firing and mechanical stoking with regard to general economy.

Automatic furnaces are more expensive, both in first cost and maintenance, than furnaces for hand firing, and in small plants they save but little or nothing in the cost of labor. In the matter of coal they have the advantage of successfully burning cheap grades of fuel that could not be used with ordinary methods of hand firing. In large plants, especially where modern coal- and ash-handling machinery is used, automatic furnaces effect a very considerable saving in labor. This, in addition to their other points of superiority, makes them more economical than hand firing in many cases.

PULLEYS AND BELTING

1254. What is a solid pulley?

A pulley in which the hub, arms and rim are one solid casting.

1255. What is a split pulley?

A pulley which is cast in halves.

1256. Why are pulleys more than 6 feet in diameter cast in halves or parts, and what is the advantage of this style of pulley over the solid pulley?

Pulleys over 6 feet in diameter are cast in halves or parts on account of the shrinkage strains in large pulley castings, which render them liable to crack as a result of the unequal cooling of the metal. This style of pulley is more readily placed on and removed from the shaft than the solid pulley, which is quite an advantage.

1257. Briefly explain the construction of the wooden pulley.

The wooden pulley is built of segments of maple wood securely glued together. Wooden split pulleys are fitted with removable bushings, so that the same pulley can be readily adapted to various diameters of shafting.

1258. What is meant by crowning a pulley face?

Making the surface curved so that the pulley will be larger in diameter in the center.

1259. What is the object of crowning a pulley face?

To prevent the slipping off of the belt sidewise.

1260. What is the proper amount of crowning for pulley faces?

From $\frac{3}{16}$ to $\frac{1}{2}$ in. per foot of width of the pulley face is usually considered to be the proper amount, although the practice of the makers of pulleys differs considerably.

1261. What is meant by the driver and the driven, when speaking of pulleys?

The pulley that imparts the motion to the belt is called **the driver**; that which receives the motion is called **the driven.**

1262. Give a rule for finding the diameter of the driving pulley when the diameter of the driven pulley and the number of revolutions per minute of each is given.

Multiply the diameter by the number of revolutions of the driven pulley and divide the product by the number of revolutions of the driving pulley.

1263. Give a rule for finding the diameter of the driven pulley, which must make a given number of revolutions per minute, when the diameter and number of revolutions per minute of the driving pulley are given.

Multiply the diameter by the number of revolutions per minute of the driving pulley, and divide the product by the number of revolutions per minute which the driven pulley must make.

1264. Give a rule for finding the number of revolutions per minute of the driven pulley, its diameter and the diameter and the number of revolutions per minute of the driving pulley being given.

Multiply the diameter by the number of revolutions per minute of the driver, and divide the product by the diameter of the driven pulley.

1265. Give a rule for finding the number of revolutions per minute of the driving pulley, its diameter and the diameter and the number of revolutions per minute of the driven pulley being given.

Multiply the diameter by the number of revolutions per minute of the driven pulley, and divide the product by the diameter of the driving pulley.

1266. What is a belt, such as used for the transmission of power?

A **belt** is a flexible connecting band that drives a pulley by its frictional resistance to slipping at the surface of the pulley. Belts are commonly made of leather, cotton, or rubber, and are united in long lengths by cementing, riveting, or lacing.

1267. What is meant by a single and a double leather belt?

A single belt is one composed of a single thickness of leather; a double belt is one composed of two thicknesses of leather cemented and riveted together the whole length of the belt.

1268. Describe the cotton belt, in use to some extent.

Cotton and duck belts are made of a number of layers sewed together and saturated with a preparation which makes them waterproof. These belts are called **two-ply, three-ply,** etc., in accordance with the number of layers or **plies** of which they are composed. **Four-ply** cotton and duck belting is about equal to single leather belting, and **eight-ply** to double leather belting.

1269. What are the advantages claimed for rubber belts?

Rubber belts are claimed to be very durable and less liable to **slip** than leather belts. They will endure a great degree of heat or cold, and are especially adapted for use in damp or wet places.

1270. How would you find the necessary length of a belt when the pulleys are already in their position on the shaft?

The necessary length of the belt can be found by passing a tape line around the pulleys, the stretch of the tape line being equal to that necessary for the belt.

1271. Give an approximate rule for finding the necessary length of an open-running belt for pulleys not in position on the shafts.

Multiply one-half of the sum of the diameters of the pulleys by 3¼, and add to the product twice the distance between the centers of the shaft.

1272. How would you find the necessary length of crossed belts?

The length of crossed belts cannot be found by any simple calculation, and, therefore, should be determined by passing a tape line around the pulleys.

1273. How wide should a belt be with relation to the tension that will be put on it?

A belt should be wide enough to bear safely and for a reasonable length of time the greatest tension that will be put on it.

1274. What is considered to be the safe tension for single belts?

Sixty pounds per inch of width of belt $\frac{3}{16}$ inch in thickness.

1275. What is meant by the effective pull of the belt?

The force tending to turn the pulley, which is the difference in tension between the driving side and the slack side of the belt.

1276. On what does the amount of tension on the driving side of a belt depend?

The amount of tension on the driving side of a belt depends on the **effective pull** of the belt, the **coefficient of friction** between the belt and the pulley, and the size of the **arc of contact** of the belt on the smaller pulley.

1277. How would you find the arc of contact of the belt on the smaller pulley, in degrees, or with respect to the circumference of the pulley?

Stretch a string over the two pulleys to represent the belt. Then, take another string, wrap it around the small pulley and cut it off so that the ends meet, and it will represent the circumference of the small pulley. Then take a third string, hold one end at the beginning of the arc of contact, as shown by the string stretched around both pulleys, wrap it around the smaller pulley, and cut it off at the end of the arc of contact. The length of the last string represents the length of the arc of contact. To find the number of degrees in the arc of contact, multiply the length of the arc of contact by 360 (the number of degrees in a circle) and divide the product by the circumference of the pulley. To obtain the fraction of the circumference, divide the length of the string representing the arc of contact by the circumference of the pulley.

1278. Give a rule for finding the width of a single leather belt for transmitting a given number of horsepower.

Multiply the horsepower to be transmitted by 33,000, and divide this product by the product of the velocity of the belt in ft. per minute and the allowable effective pull in lb. The quotient will be the width of the belt.

1279. Give a rule for finding the horsepower that a single leather belt will transmit.

Multiply together the effective pull in lb., the width of the belt in inches, and the speed of the belt in feet per minute. Divide the product by 33,000.

1280. Why should a belt be run at as high a velocity as conditions will permit?

Because the higher the velocity, the greater is the horsepower that the same belt will transmit, or the higher the velocity, the less may be the width of the belt to transmit a given horsepower.

1281. What is the maximum velocity allowable for a belt?

For a laced single or double leather belt the maximum velocity allowable is about 3,500 feet per minute. For belts spliced by cementing, the velocity may be as high as 5,000 feet per minute.

1282. Why is a double belt able to transmit more power than a single belt?

As the effective pull for a single belt is based primarily on the strength through the lace holes, a double belt, which is twice as thick, is able to transmit twice as much power as a single belt, and even more than this, where the ends of the belt are cemented instead of laced.

1283. Why is the width of a double belt required to transmit a given horsepower generally assumed to be seven-tenths the width of a single belt to transmit the same power?

For the reason that where double belts are used on small pulleys, the contact with the pulley face is less perfect than it would be if a singe belt were used, owing to the greater rigidity of a double belt. More work is required also, to bend the belt as it runs over the pulley than in the case of the more pliable single belt, and the centrifugal force tending to throw the belt from the pulley also increases with the thickness.

1284. Give a rule for finding the width of a double leather belt for transmitting a given number of horsepower.

Multiply the horsepower to be transmitted by 23,100. Divide this product by the product of the velocity of the belt and the allowable effective pull per inch of width for single belts.

1285. Give a rule for finding the horsepower that a double belt will transmit.

Multiply together the effective pull on a single belt 1 in. wide, the width of the belt, and its velocity. Divide the product by 23,100.

1286. Which side of the belt should be run next the pulley?

This is a much disputed question, although the general practice is to run the belt with the hair or grain side nearest the pulley. . This side is harder and more liable to crack than the flesh side. By running it on the inside the tendency is to compress it as it passes over the pulley, while if it ran on the outside, the tendency would be for it to stretch and crack. For this reason the life of the belt will be longer if the wear comes on the grain side.

1287. Why should the lower side of the belt be the driving side?

Because the slack side will then run from the top of the driving pulley, and the sag of the belt will cause it to encompass a greater length of the circumference.

1288. Why do long belts, running horizontally, work better than short belts?

Because their weight holds them more firmly to their work.

1289. Why is it objectionable to use resin to prevent the slipping of belts?

Resin gums the belt, causes it to crack, and prevents slipping for only a short time.

1290. How may the slipping of a belt be remedied?

If the belt is in good condition, properly tight, and persists in slipping, a wider belt should be used. Sometimes larger pulleys on the driving and driven shaft may stop the slipping, as they increase the belt speed and reduce the stress on the belt.

1291. How may leather belts be kept soft and pliable?

Leather belts may be kept soft and pliable by oiling them once a month with castor oil or neatsfoot oil.

1292. What causes the flapping of the slack side of a belt and how may this trouble be remedied?

Flapping may be due to one or more of the following causes. (1) One or both of the pulleys may run out of true, and the belt is alternately stretched and released. If the belt is rather slack, tightening it somewhat may cure the trouble, but the best remedy is to turn the pulleys to run true. If it is not possible to turn the pulleys true, the belt speed should be lowered a little, either by the use of smaller pulleys or by changing the speed of the driving shaft, according to circumstances. (2) Pulleys being out of line with each other are another source of flapping. The remedy is to bring the pulleys in line. (3) With belts running at speeds above 4,000 feet per minute, flapping may occur even when the pulleys are perfectly true and in line with each other, and the belt has the proper tension. This is believed to be due to the entrapping of air between the face of the pulley and the belt. Such flapping may be remedied by perforating the belt with a series of small holes. (4) Lack of steadiness in running will produce flapping. The only cure is to take such steps as will insure steady running. Increasing the weight of the flywheel on the engine, or placing a flywheel instead of a pulley on the driven machine, may remedy the trouble. (5) If the belt is not joined square, this will also cause flapping. The remedy is to unlace or unfasten the joint and make it square. (6) Too great a distance between the pulleys may also cause flapping. The remedy is to have the distance between pulleys not greater than 15 feet for belts up to 4 inches in width; 20 feet for belts above 4 and below 12 inches; 25 feet for belts above 12 and below 18 inches; and 30 feet for larger belts.

1293. What is considered to be the proper tension for horizontal belts?

When a belt in motion has about 1 inch of sag on the slack side for every 8 feet between pulleys, it is considered to have the proper tension.

1294. How may the ends of a belt be joined?

They may be joined by **lacing, sewing, riveting,** or **cementing.**

1295. What precaution should be taken before proceeding with the lacing of a belt?

The ends of the belt should be cut square, using a sharp knife and a try square. The holes punched in each end of the belt should be exactly opposite each other, using 3 holes in belts up to 2 inches wide, and 5 holes in belts between 2 and 3 inches. For belts up to 4½ inches wide, two rows of holes should be punched, using 3 holes in the row nearest the joint and 2 holes in the second row. For belts up to 6 inches wide, 4 and 3 holes should be used. For belts larger than 6 inches wide, the total number of holes in each end should be 1 or 2 more than the number of inches of width, in order to get an odd total number of holes. The outside holes of the first row should be away from the edges of the belt at least ¾ inch, and the first row should be away from the joint at least ⅞ inch. The second row should be at least 1¾ inches from the end. The lacing should not be crossed on the side of the belt that runs next to the pulley. Before proceeding with the lacing of a belt, it is well to make sure that there is no twist in the belt, or, in the case of a crossed belt, that it has not been given a wrong twist.

1296. Explain how the ends of a belt are joined by cementing.

After the ends of the belt are pared down with a sharp knife, warm them near a fire, apply belt cement while it is hot, and press the joint together between two boards. Belt cement can be obtained of any dealer in engineers' supplies. The directions found on the can should be carefully followed.

1297. If belt cement cannot be obtained, how can a belt cement be made by the engineer?

A good belt cement can be made by melting together over a slow fire 16 parts of gutta percha, 4 parts of India rubber, 2 parts of pitch, 1 part of shellac, and 2 parts of linseed oil, by weight. All ingredients should be cut very small, mixed well, and used while hot.

1298. What are the disadvantages in joining the ends of a belt by cementing?

The serious disadvantage is that the stretch of the belt cannot be readily taken up, as in the case of laced belts, and **idlers or tightening pulleys** must be used when the center-to-center distance of the pulleys is not adjustable.

1299. To what extent do belts stretch with use?

New leather belts will stretch from ¼ to ½ of an inch per foot of length. Rubber belts are said to stretch continuously. Cotton and duck belts are said not to stretch with use.

1300. What precautions must be observed when using rubber belts?

Animal oils or animal grease should never be allowed to touch them. If the belt should slip, it should be lightly moistened on the side nearest the pulleys with boiled linseed oil.

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